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IMPROVEMENT OF THE PORT OF PHILADELPHIA.

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Navigable water is essential to the existence of a commercial city, and it was largely due to the facilities for effecting a landing that this site was selected by the founders of Philadelphia.

But in the two centuries that have passed, the city has outgrown the limits of its deep water frontage, and although its shore line bordering a navigable river, has an extent of nearly twenty-five miles from the Poquessing Creek to Fairmount, but a limited portion of it is available without incurring great expense.*

* The importance of this discussion is confirmed by the accompanying extract found in the Philadelphia *Record*, September 23, 1887, a few days after this paper was completed. L. M. H.

A FOREST OF SPARS.—VESSELS IN PORT THAT CANNOT BE UNLOADED. —*The City's Growing Commerce Retarded by Inadequate Wharfage.—Corporations Monopolizing the River Front.*—Within the last few years the

The deepest water is to be found in the six mile concavity extending from Greenwich Point to just above Port Richmond Of the remainder about eight miles are cut off by the Five Mile Bar, stretching from the head of Petty's Island to Point No Point; seven miles are included in the Schuylkill River, which is only about 400 feet wide, and the rest is covered by the Horse-shoe Shoals.

Above Five Mile Point, there are twenty-six feet of water very nearly to Torresdale, with the one exception of a cross-over bar opposite the House of Correction, having on it over eighteen feet. Moreover, sixteen feet of water can be carried at mean low tide almost to the mouth of the Delaware and Raritan Canal, by removing the one short confluent bar at Kinkora, thus greatly augmenting the carrying trade by river and reducing the cost of transportation. The commerce of the upper river to and from Bordentown for the year ending December 31, 1885, is estimated to have been 1,135,942 tons, independently of the freight and passengers carried by the daily steamers from Philadelphia to points above.

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commerce at the port of Philadelphia has been on a steady increase despite the inadequate facilities at hand for the reception of traffic, until to-day the sorry sight is presented of a harbor teeming with heavily-laden vessels that must wait for days before wharfage can be procured for the discharge of their cargoes.

At the present time there is more shipping anchored in the Delaware River between Port Richmond and the League Island Navy Yard than ever before in the history of the port. Looking southward from Dickinson Street yesterday, the eye encountered a great number of idle vessels, whose spars, looming up toward the sky, resembled a vast forest. In this great fleet of the merchant marine all the nations of the world were represented and every description of cargo included, from East India jute to the common article of commerce—Spanish iron ore. The detention of this vast amount of traffic at the entrance to the second city of the Union is due solely to the lack of available places at which to discharge it. The scarcity of wharf property arises mainly from the fact that nearly every foot of wharfage from Clearfield Street to Moore Street is either under corporate ownership or control, or has been rendered valueless through the refusal of the railroad companies to introduce the necessary sidings and connections that would prevent the necessity of handling goods a second time.

In many cases wharf charges are maintained at such an exorbitant rate that vessels have been driven away by the excessive tolls. Another impediment to the natural growth of the port is the contracted dimensions of many of the docks, which are too small to admit of the docking of vessels, so that they will not project into the river to the danger of passing craft. In other

Concerning that part of the Delaware within city limits, and lying above Petty's Island, the Advisory Board to the Harbor Commissioners, of which Capt. G. B. White, is Chairman, says,* "It is almost in a state of nature, but has great qualifications for commercial frontage. The main channel lies in great bends, but these are favorable to bold frontage. Were the river straight, the channel would be midway between the two shores, and wharves of at least 1,000 feet in length would be necessary to reach the border of the ship channel." * * * "In short, the natural advantages of this whole frontage above Bridesburg are unusual." He adds, "The city front above Richmond has been but little utilized, because of the great shoal that has accumulated in the neighborhood of Five Mile Point, and which the General Government now designs to remove in part. Should the Government be successful, the water front that the city offers above will be appreciated because of its bold banks and handy channel." In a letter to the Harbor Commissioners, dated February 13, 1886, the Advisory Board says: "The portion of the (port-warden's) line above Richmond has been located with due reference to the works of channel improvement undertaken by the General Government above Petty's Island. The improvement, while it does not conform in plan and disposition of works to that suggested in 1883 by your Advisory Board, promises to lead in the same direction, and inspires much hope of success.†

In his annual report for 1883, General Weitzel, U.S.E, then in charge, said, "It will be a matter of great expense and difficulty

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cases the docks are so badly dredged that deeply-laden vessels are in peril of being strained to pieces with the flow and ebb of the tide. At the same time wharf property has risen in value until a twenty-foot front anywhere along the river would bring at public sale not less than $30,000.

Among the large steamers lying in the river awaiting their turn to discharge are the *Kairos, Hungaria, Cid, Regina, Romanby, Parklands, Acuba, Pensher, Roseville, City of Newcastle, Cairo, Haverstoe, Madrid* and *Earnmoor*, besides a large fleet of sailing craft, composed mostly of ice schooners, with an aggregate capacity of 30,000 tons. On the steamships enumerated there are afloat 50,000 tons of iron ore alone. The Spanish steamship *Leonora*, from Havana, which arrived in port last night, with over 4,000,000 pounds of sugar, was unable to go into her dock, and was swung around lengthwise in the river, blockading the ends of three piers.

* February 25, 1886.

† See the *Supplement* to this paper.

to obtain a channel under Five Mile Point, sufficiently deep to meet the requirements of this up-river commerce."

Captain Heuer, U.S.E., in charge in 1884, reports in substance as follows: "The plans of the Advisory Board contemplated a bulk-head, wing-dam or obstruction of some kind, about 3,000 feet in length, from Fisher's Point, on the New Jersey shore, to deflect a large portion of the ebb tidal flow." * * * "To meet the increased volume of tidal flow on the Philadelphia side, and avoid too serious a scour in the wharves, it would be necessary to cut away a portion of one side of Petty's Island, and build up on the opposite side of the same, putting a bulk-head around portions of the new shore lines of the island.

"The first step would be to build out a dike from Fisher's Point, as far as necessary, and watch the effect on the channel between Petty's Island and Philadelphia; it would certainly deflect an increased tidal flow down the channel. It might scour close to the wharves on the Philadelphia side, and endanger these, and to prevent this it was deemed necessary to cut away the lower end of Petty's Island." The approximate estimate for this improvement is put at $1,010,460, of which but $30,000 are for the dike; the balance, or $980,460 are then intended to counteract any injurious effects it may produce.

The suggestions reported to General Weitzel, in November, 1883, contemplated closing the south channel by a dike extending from Fisher's Point to the head of Petty's Island, and thus throwing the whole of the ebb prism into the north channel. This, it was estimated, would require a sectional area of about 55,000 square feet, and "necessitate the removal of upwards of 6,000,000 cubic yards of material."* At thirty-five cents per yard, this one item would then be over $2,100,000, exclusive of the cost of the dike, land-damages, etc.

From this it appears that the Five Mile Bar is the key to the upper river, not only for general but for local commerce, and the opening of a suitable channel through it will render a large and valuable frontage, immediately available, yet the expense, according to the plans proposed, is almost prohibitory. A consideration of the physical features of the bar, the causes of and the efforts to remove the same, with some suggestions as to improved and more

* *Report of Chief of Engineers*, 1884, vol. i, p. 868.

economical methods of accomplishing this end, become therefore questions of great commercial and financial interest to the City as well as to the General Government.

DESCRIPTION OF FIVE MILE BAR.

This deposit of fine sand forms a submerged ridge, extending from a point in the Pennsylvania channel below the head of Petty's Island, in an easy curve to Harrison's Wharf at Five Mile Point, a distance of about 8,000 feet. It occupies the neutral ground between the paths of the flood and ebb resultants, and being composed of light material, is readily affected by the opposing forces to which it is subjected. These are the flood and ebb tidal prisms, and the fresh water drainage flowing in different paths and with variable intensities as affected by the form of the river bed above and below the bar.

How these forces have been modified by various artificial changes in the banks of the river can best be seen by examining their effects upon this plastic mass of material at different dates and comparing notes as to position, quantity and direction. Hence the great value of the accurate comparative surveys which the Government has made at various times. Such a comparison to be thorough and reveal the whole truth should be made with reference.

(1.) To the *linear features*, as the crest line, the contours, the thalwegs and the slopes.

(2.) To the *areas*, as showing the relative sizes of the sections, not only of the bar, but also of the fluid prism constantly playing upon it.

(3.) To the *volumes*, as showing the mass movement in cubic measure.

(4.) To the *dynamics*, as indicating the measure of the forces and resistances, their lines of direction, degree of relative permanence or variation, and duration of action. The resultant effect being the *difference* of movement produced by these forces, hence the slowness of the changes in tidal rivers.

"In alluvial bottoms the channel is the cast of the living waters within; it is not the independent mould into which the river is turned, but it is the trough hollowed out by the running water, and it alters its form and direction with every change that may be induced upon the flow." *

* G. B. White, Captain U.S.N.

In subjecting the bar in question to this scrutiny, it becomes necessary first to state the simple mechanical law by which the effect may be measured.

THE MATHEMATICAL PRINCIPLE.

If a flexible but straight line *A B* be acted upon by a series of equal and opposite forces in any direction, the line will remain straight, but if any of the forces be augmented or diminished in intensity, the line will become bent in a direction away from the greater force until the equilibrium is restored or the line broken.

FIG. 1.

Thus, in the diagram (*Fig. 1*), if a system of forces in equilibrium be increased by the amounts represented in broken lines, the straight line *A B* will become flexed in the direction of *C*. The same effect would result from a decrease in the intensities of the opposing forces. It is thus that the flexure of a curve as shown from a comparative chart will indicate the changes that have taken place in the forces producing these effects.

THE APPLICATION TO THE CREST OF THE BAR.

An examination of *Plate III* will show at once the marked changes that have occurred in the form and position of the axis of Five Mile

Bar, since the survey of 1843. At that date the concavity, as shown in the dotted curve, was greatest, indicating an excess of pressure from the flood tide rolling up the northern channel. During the intervening years the crest line has been gradually flattened out until the direction of its curvature has been reversed. The greatest movement having been about 810 feet. The diagram shows the relative amounts and dates of these changes.

These effects may be due to a diminution in the flood forces, an increase in the ebb, or a change in direction of either caused by auxiliary works.

As by far the larger part of the volume of the stream is composed of tidal waters, and as there is nothing to augment this volume from year to year, but on the contrary much to diminish it, we may presume at once that the ebb forces have not increased but that there has been a sensible diminution of the flood since 1843, whereby its velocity at this point has been so diminished as to produce deposits and to permit the neutral axis to recede. We must seek the cause for this effect down the river, and have not far to go, for, on examining the earlier and later maps, it will be seen that at the lower end of Petty's Island, the north or flood channel has been seriously throttled by the extensions of the pier-heads on both sides, more especially by those at the Port Richmond coal wharves and below. In response to inquiries as to the dates of construction of these wharves Mr. H. K. Nichols, Chief Engineer of the P. & R. R.R. Co., replies that "the northern tier of wharves was finished in 1843." (These are the shortest wharves, and from this it appears that they were built in the year of the survey. They are shown on the chart.) He adds:

"To the south, including No. 14, finished in 1845.

"In 1854, finished to and including No. 18.

"In 1862, Nos. 4, 6 and 8 extended." (How much is not stated.)

"In 1865, No. 14 extended." (How much is not stated.)

"In 1866, Nos. 19, 20 and 21 completed.

"In 1867, Nos. 13 and 18 extended. Several other extensions were made, the dates of which were not found."

The actual condition of these works and their relation to the channel will be seen on *Plate II*, taken from the U. S. C. S chart of 1878, scale 800 feet to 1 inch.

The wharf of the Kensington (City) Water Works, which extends to a considerable distance, was built about 1849. That of the Port Richmond Iron Works (I. P. Morris & Co.*) was built in 1839 and extended twice; the first time in 1850, 100 feet, and again in 1869, 187¾ feet, making a total extension of 287¾ feet. The original wharf extended about 520 feet from Bank (now Beach) Street. It is now 760 feet beyond the east side of Beach Street and about 380 feet beyond the low water line of 1847.

The wharf of Wm. Cramp & Son, at the foot of Norris Street, extends to a distance of 612 feet from the east line. It was prolonged 156 feet 9 inches in 1870 to the present port warden's line, which was established April 5, 1849. In 1843, none of these wharves were completed.

In addition to these extensions, there are others on the north bank of Petty's Island which have aggravated the injury to the channel above by materially reducing the flood volume and so weakening it as to destroy the former position of equilibrium between flood and ebb at the crest of the bar.†

This movement is also shown by the contours and sections which have followed the general direction of the crest. The various fathom curves of the north or flood channel have fallen back about 1,000 feet, while the corresponding south channel contours have advanced as the ebb wedged its way between the bar and the south shore, eroding and compressing the southern slope of the bar.

The cross-sections (*Plate IV*) taken on the line *A B*, of *Plate II*, at intervals of 1000 feet exhibit the shifting in the position of the fulcrum and weights, as in a scale beam. In section No. 1 there was no trace of the bar in 1843, and the flood channel was nearly the same as the ebb, there being only a difference in the slope of the two banks. In section 2, the terrace is seen at about 12½ to 13½ feet depth. In No. 3, a low bar with 12 feet of water, flanked by channels of equal depth. In the succeeding sections the bar becomes higher and the flood channel deeper and wider, reaching its maximum in section No. 5, 5,000 feet below the point.

* Information obtained through the courtesy of Mr. John T. Morris, President.

† On May 8, 1883, Prof. Henry Mitchell estimated the reduction of area from this cause to be eleven per cent., "with very little change of channel depth."

In the later surveys, the rapid growth of the bar, increase of ebb, and diminution of flood sections are so clearly shown as to require no further comment at this place, where it is intended merely to call attention to the relations between the flood and ebb forces.

Measurements of these sections by the planimeter also show a gradual diminution in sectional area of the water prism; that is, notwithstanding the great variations in width, there has been a shoaling which increases in the down-stream direction, indicating a diminution of the scouring forces as the head of the island is approached.

The accompanying table is confirmatory of these conclusions and contains many valuable suggestions; for example: Columns 3 and 4 show that the filaments of *maximum* flood and ebb cross each other between sections 1 and 2 (see chart, *Plate II*) and that the ebb is greater at section 1, and slightly less in 2 and 3. In section 8 it is the greater in the south channel where it reaches the unusually high value of 4·52 feet per sec., and the flood is greater in the north channel, 400 feet from shore. In column 5 it is observed that the *mean* velocities of the ebb are greater than those of the flood excepting at No. 8 north, where the mean flood velocity is 2·98, and the ebb 2·90. Hence it is safe to infer that *the volume of the ebb may be somewhat increased through this section* without producing any serious damage to the pier heads or to the channel, and without increasing the section by artificial means, but on the contrary, the result of such increase of volume would be highly beneficial. To increase the section for a small increase of ebb volume would prove injurious, as it would reduce the working power of the stream. It is also evident that there is an excess of ebb volume passing through the south channel, a portion of which may be deducted without injury to the latter, and with great benefit to the north channel.

Comparing the total area of section 8 (north and south) with those of 1, 2 and 3, as stated in column 9, it appears that at both flood and ebb, 8 is 20 per cent. greater than 1; 22 per cent. less than 2, flood; 20 per cent. less than 2, ebb; 24·8 per cent. less than 3 flood, and 23 per cent. less than 3, ebb, so that section 8 as a whole is more than large enough to pass all the water that reaches section 1, but not large enough to supply sections 2 and 3, and still maintain its velocity, hence the shoaling in the reach.

TABLE SHOWING THE ELEMENTS OF THE CROSS-SECTIONS AND DYNAMIC CURVES AT AND NEAR FIVE MILE BAR, DELAWARE RIVER, PHILADELPHIA.*

1	2	3		4		5		6				7		8			9		10		11		12
Sections	Widths at Maximum Flood Tide.	Maximum Velocities reduced to Mean Tide. (In Feet per Second.)		Distance from Origin to Point of Maximum Velocity. (In Feet.)		Mean Velocity. (Feet per Second.)		Distances to Loci of Mean Velocity, or, Location of the Principal Working Part of the River.				Width of Portion of Stream, in which the Velocity exceed the Mean. (Outside Lim.)		Depth at Time of Maximum Velocity in Feet, below Mean Low Water.		Distance from Origin.	Area of Sections in Square Feet.		Distance to Line of Mid-Areas in Feet.		Distance to Axes of Mid-Volumes.		Remarks.
No.	Ft.	Fl'd	Ebb	Fl'd	Ebb	Fl'd	Ebb	Flood.		Ebb.		Fl'd	Ebb	Fl'd	Ebb	Ft.	Fl'd	Ebb	Fl'd	Ebb	Fl'd	Ebb	
1	2550	3·11	3·57	2000	1300	2·61	2·81	542	2311	831	2078	1769	1247	42·25	41·50	1900	51825	49922	1590	1590	1613	1575	The maximum flood is 0·75 foot higher than maximum ebb. Hence, the difference in depths, areas, etc.
2	5820	3·17	3·13	1300	2400	2·05	2·20	158	2700	900	3388	2542	2488	28·35	27·60	2500	76172	71822	2575	2585	1841	2404	
3	5900	2·85	2·79	1500	3000	1·95†	2·17	882†	4223	912‡	4522	3341	3610	31·05	30·30	1200	77806	73447	2664	2649	2254	2625	
8 N.	1350	3·38	3·30	400	1000	2·98	2·90	214	934	280	1025	720	745	37·00	36·25	100	33865	32785	504	504	520	542	On north side of Petty's Island.
8 S.	1900	2·88	4·52	600	700	2·35	3·26	233	922	390	963	759	573	36·10	35·35	600	28485	27045	790	790	733	783	On south side.
	3250	3·13 mean	3·91			2·66	3·08										62350	59830					

* Collated and extended from the data collected and computed by Mr. Marindin, Assist. U.S.C. and G. Survey, and embodied in the Report of Prof. Henry Mitchell on *A Physical Survey of the Delaware River*, Appendix No. 9, *U. S. Coast. Survey Report for 1878.*

† As the flood passes up over Section No. 3, the portion of its prism, 307 feet wide, lying between 2,100 and 2,407 feet from shore, has its velocity diminished to a minimum of 1·76 feet per second in passing over the foot of the bar.

‡ The ebb at this section passes several times from maximum to minimum values, thus dividing up into three streams.

The times of transit through the north and south channels are also different, producing some interference and deposit at both ends. Columns 10 and 11 show on which side of the mid-area the loci of mid-volumes of flood and ebb are situated, and the great divergence between these latter resultants in sections 2 and 3. In 1 and 8 their paths are more nearly coincident, and hence their useful work greater.

It will be seen that the loci of mid-volumes cross between sections 1 and 2. In 1, the locus of the resultant of the ebb stream is thirty-eight feet to the north of that of the flood, in 2 it is 563 feet to the south, and in 3 it is 371 feet distant but on the same side.

Again, if the limits of mean velocities of flood and ebb be located, as given by their co-ordinates in Column 6, it will reveal the position of the more vital part of the stream lying between them. Its breadth is stated in Column 7, where it appears that at section No. 1 the major part of the flood is 522 feet wider than the ebb.

At No. 2, these prisms are of nearly equal width, although their resultants are widely separated, being, as stated, 563 feet apart; the flood axis running near the crest of the bar, the ebb over the thalweg. What is needed there is a structure that will draw in the ebb and deflect a portion of its volume to the other side. This is more fully confirmed by an examination of section No. 3. Here it is found that the flood in the north channel is divided, by the foot of the shoal, into two parts, in which the velocity exceeds the mean (1′·95). The minor prism passing over the shoal is but 307 feet wide, and has a velocity diminishing to 1′·76 at 2,200 feet from the Pennsylvania shore. The ebb in the same (north) channel is also divided into two streams, having velocities above the mean (2′·17), located as follows: The smaller one, between 912 and 1,444 feet from shore, with a maximum velocity of 2′·81 at 1,200 to 1,300 feet. This 100-foot prism has the greatest velocity in the section. The larger ebb prism lies between 2,183 and 4,527 feet from the origin and is consequently nearly half a mile wide. It is divided near its northern limit by the head of Petty's Island (at 3,000 feet), where the greatest velocity, 2·79 feet, is found for a width of 800 feet; that is, from 2,600 to 3,400. This causes a small portion of this ebb prism to traverse the region just north of the island, and maintains the nar-

row channel it has created along its path. Between these two more rapid streams lies a retarded prism, extending from 1,444 to 2,183 feet, or 739 feet wide, in which the velocities diminish to 1'·79 at 1,600 feet out, due to the bar over which it has just passed. These phenomena are characteristic of streams undergoing contraction and are produced by the reaction of the banks in causing an increased velocity near them, which produces the scour near shore and the low spur in or near mid-stream. The remedy here then consists in throwing a larger volume of the ebb into this shore channel along Petty's Island by a reaction dike, at the head of the island, which shall draw off a part of the ebb from the south channel and cause it to traverse the northern one. Such are some of the deductions from these data, which are believed to be sufficient to explain the physical phenomena of the changes produced at this site and to enable the engineer to apply the remedy.

HISTORY OF THE IMPROVEMENTS.

As the lessons of experience are of great value in projecting works and avoiding unnecessary expense, it becomes an important element to ascertain what has been done, if anything, and what have been the results. To this end the history of the work is indispensable.

In the *Report of the Chief of Engineers for 1884*, p. 794, the statement is made by the resident engineer, then in charge, that the improvement of Five Mile Bar is an important but

> "At the same time a very difficult one to treat, owing to misjudgment on the part of the city authorities of Philadelphia, having allowed the wharf line to extend far beyond its proper position in rounding the point. Many wharves have been built out to this line, and have proved a serious source of shoaling in many parts of the channel below. A curtailment of these wharves will probably be a part of any thorough scheme of improvements, but as this would entail very great outlays of money at the present time, other means have been employed to enable the commerce of the river to pass this point, viz., cutting a channel during December, 1881, and January, 1882, at the upper end of Petty's Island. This channel was subsequently widened to 200 feet, with an allotment of $4,500. It should be deepened to twelve feet at mean low water, and an appropriation of $5,000 should be made for this purpose."

The premises in the above statements being at variance with the facts, the conclusions must be at fault, as there are believed to be but two short wharves at Five Mile Point, and these are not

used to any extent, nor are they thought to have produced any serious shoaling in the channel.

In 1881, a channel was dredged across this bar to a depth of 9 feet, with a width of 75 and length of 700, at a cost of $2,500. The price was $38\frac{8}{10}$ cents per yard. It was regarded as a temporary expedient only, and no degree of permanence was anticipated. In fact, upon investigation, at the end of the year, the channel was found to have shoaled to within one foot of its original depth.

Subsequently, the existence of a narrow but straight channel was discovered close under the upper end of Petty's Island. It was thought that if this were improved, it would, in all probability, maintain itself. It is believed to have been caused by the building up of the submerged end of Petty's Island by a bulk-head.

This channel was enlarged in 1881–82, to a depth of 9 feet, width of 100 feet, and length of 800 feet, by the removal of 6,500 cubic yards at 41 cents, making a total of $2,665. It was found to have silted up soon after to a width of 75 feet, and was widened in 1883, to 200 feet by the removal of 11,566 cubic yards at 35 cents, costing $4,048.10.

These attempts to improve the channel by dredging having proved abortive, the Advisory Board to the Harbor Commissioners recommended three plans;* first, to close the south channel by a dike from Fisher's Point, and the cutting off of part of the north side of Petty's Island; second, the closing of the south channel, making a basin of that part of the river, and, third, the building of a short dike from the Jersey shore, and a cutting away of the north, and extension of the lower shores of Petty's Island, either of which would cost about $1,000,000. The plan recommended by the Government engineer was but a slight modification of the latter and was estimated at $955,290.

Again, in their *Preliminary Report on the Permanent Improvement of the Delaware River*, dated Philadelphia, January 23, 1885, the Board of Engineers say:

"The deepening of necessity must be done either by artificially dredging the shoal spots, or by increasing the power of the current at these points by contracting the channel, or by concentrating a larger volume of water where they occur, so that by its scouring action the obstructions may be washed away." * * *

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* *Report of Chief of Engineers*, 1885, p. 805.

"After considering the various plans submitted for the improvement of the upper part of the harbor in front of the city of Philadelphia, each of which contemplates the cutting away of a part of Petty's Island, and after making a personal examination of the locality, the Board concluded that an increased tidal flow through the west (north) channel near the head of the island, sufficient to secure the increased depth and width required, could be procured by a deflecting dike, starting from Fisher's Point, and running down stream in a slightly curved direction, sensibly parallel with the pier-line of the Pennsylvania shore opposite, extending toward the head of Petty's Island, as far as might be necessary for the purpose of diverting into the west (north) channel a considerable part of the ebb tidal volume now passing down the east (south) channel." * * * "It is probable, however, that in the construction of this dike an injurious scour may occur at and beyond its outer end, to prevent this a mattress-sill of brush not more than three feet in thickness should be kept well in advance," etc.

Beyond the American Ship-Building Company's yards, "it is thought that a depth of twelve feet will be sufficient for the wants of commerce for a long time in the future."

Assuming the sill to extend all the way to Petty's Island, the Board's estimate for the dike was $87,570, and there was added for dredging $462,000, making a total of $549,570 for the improvements at this bar. The dimensions finally adopted for the dike are stated in a letter of the engineer in charge, under date of October 9, 1885, as published in the *Report of the Chief of Engineers for 1886*, p. 820, as follows:

"The dike is to extend from Fisher's Point, N. J., 3,000 feet toward the head of Petty's Island, with a mattress sill about 3 feet thick, projecting 500 feet farther, leaving an open channel way of about 3,000 feet between the end of the sill and the island." * * "The top of the dike is to be at the level of mean low water, allowing the tides to flow over it." * * * "The dike is evidently designed to throw more water into the channel west of Petty's Island. Work upon it was commenced in August, 1884, but stopped by an injunction in September."

The Board of Engineers, in reporting on the testimony taken during the injunction proceedings, under date of October 28, 1885, says: "It does not appear to the Board that there any other means available of successfully maintaining the requisite channel depth in this part of the Delaware River than those which they have heretofore proposed, and they recommend, therefore, that the construction of the Fisher's Point dike be continued and completed." This was accordingly done, and the dike was finished

in conformity with the plans and dimensions heretofore given, on June 30, 1886, at a cost of $39,560.28.

To expedite the formation of a channel, under the influence of the dike, a cut was made in the path of the ebb and flood currents across the bar in May, June and July, 1886, when 125,000 cubic yards of material were removed at nine cents, costing $11,250.00.

Of this work, the engineer in charge says in his report for 1886:* "The object of the dredging in progress is the formation of a channel twelve feet deep at mean low water, connecting the deep water above with the deep water below the bar. This will afford great relief to the commerce moving between Philadelphia and the river above. This channel is not supposed to be permanent, but its value is so great as to be worth some cost in maintaining it."

Thus, up to this date, there had been expended altogether in the efforts to improve this locality, $60,023.38.

THE EFFECTS PRODUCED BY THESE IMPROVEMENTS.

To determine the results of the dredging completed in July, 1886, and of the dike finished the month before, a re-survey was made in May, 1887, when it may safely be said that not a trace of the cut, which was made 125 feet wide, 2,500 feet long, and 12 to 16 feet deep, but ten months before, remained. How much sooner it filled up is not known, but as the material is very fine, and as a lateral pressure was produced by the dike, its closure was probably very rapid. By examining cross-section No. 2, which intersected the upper, and No. 3, the lower end of the cut, it will be seen, by comparing the surveys of August, 1886, and May, 1887, that it is entirely obliterated, and the same result is revealed by the charts of the soundings and by the contours.

The effect of the dike upon the bar is also shown by these cross-sections, as well as by the plan of the crest lines already referred to (*Plate III*). On cross-section 1, the crest of '87 lies to the left of all previous positions, and it is slightly higher, indicating increased shoaling at that place; on No. 2, it is slightly to the right, the point of inflection being between these sections, and it is about a foot lower than in '78 and '82 (that of '86 was cut down by the dredging); in No. 3, it is seen to the right of '86, with same depth,

* Page 805.

under '78 with a gain of a little more than three feet in depth, and a still greater gain over '82. During the interval since the completion of the dike, which is abreast of Sections 2, 3 and 4, however, there appears to have been a slight erosion from the brow of the southern, or ebb, slope, and a filling up of the cut.

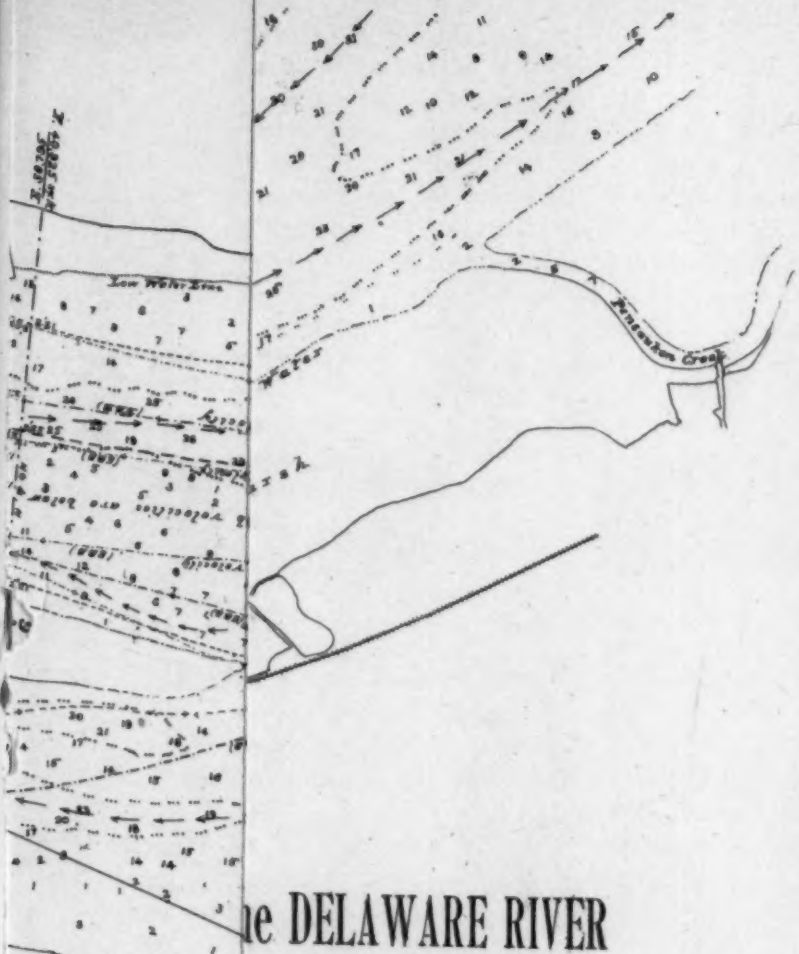
The conclusion to be drawn from this is, that if a dike be intended to increase the scour through a cut, it should be placed at such a distance *above* it that the increased velocity may be acquired before the water enters the cut, and not abreast of it where the wedge-like action of the stream compresses its outer bank and tends to crowd it over into the cut.

In section No. 4, the surveys of 1886 and 1887 show the crests as nearly coincident, with an increase of deposit on the right or flood slope and shoaling in the flood channel. As compared with its position in 1843, there has been a northward movement of about 800 feet, and a loss in depth of three and one-half feet. In No, 5, below the end of the dike, there is a gain in depth on the crest of about one foot. The flood channel is very much contracted as compared with that of 1843. No. 6, shows practically no change from 1886; the salient end of the ebb channel terminates under the former crest of 1843. These cross-sections further show that in 1843, there was a good and wide twelve-foot channel on the north or Pennsylvania side of the river across the bar. In general then it may be concluded that, between the dates of the last surveys, the dike had produced a deepening of about one foot along a portion of the crest and had compressed or rolled the bar to the northward, at the point of maximum movement between sections 3 and 4, or abreast of the end about 150 feet, and changed the direction of its curvature from a line nearly straight to one which is concave. The greatest depth along the crest is now but eight feet for a short distance, with five-foot spots in the immediate vicinity.

THE PROPOSED REMEDY.

From the statements and opinions already cited, it appears that the resources of the projectors of the several plans have been limited to dredging or to current concentration by means of dikes, extending from the shore in such a direction as to canalize the channel and contract the water way, thus affecting to a greater or lesser extent the entire volumes or prisms of the flood and ebb, and

Plate II.

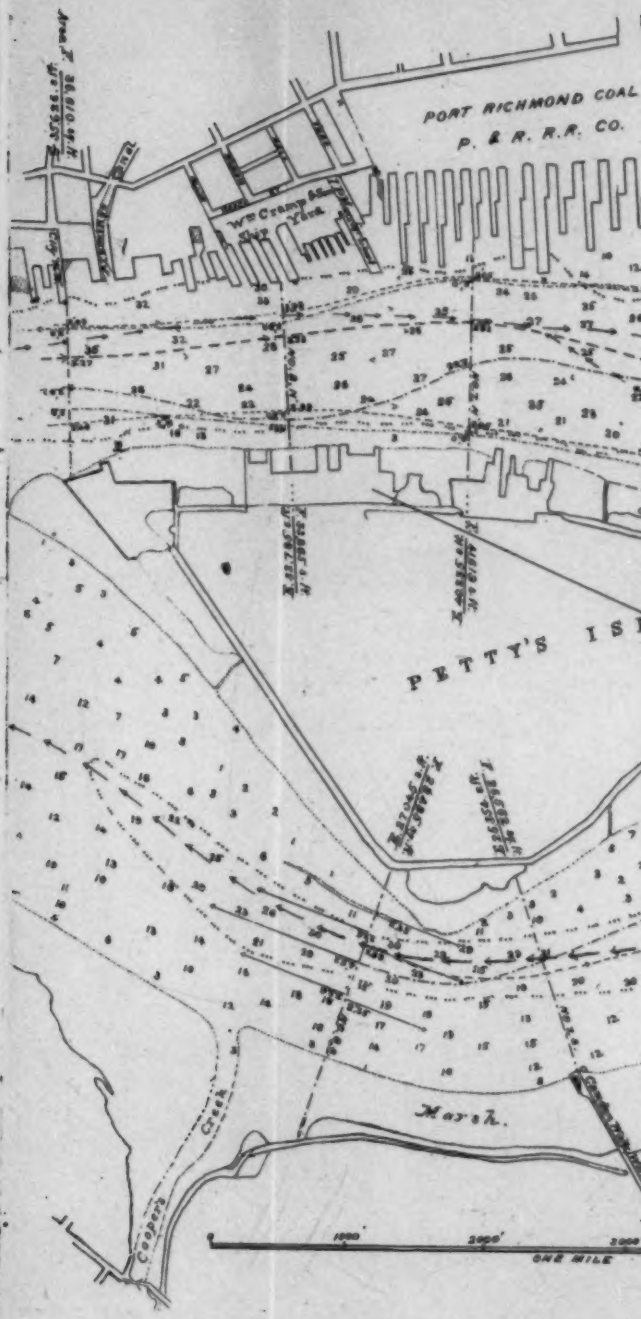


ne DELAWARE RIVER

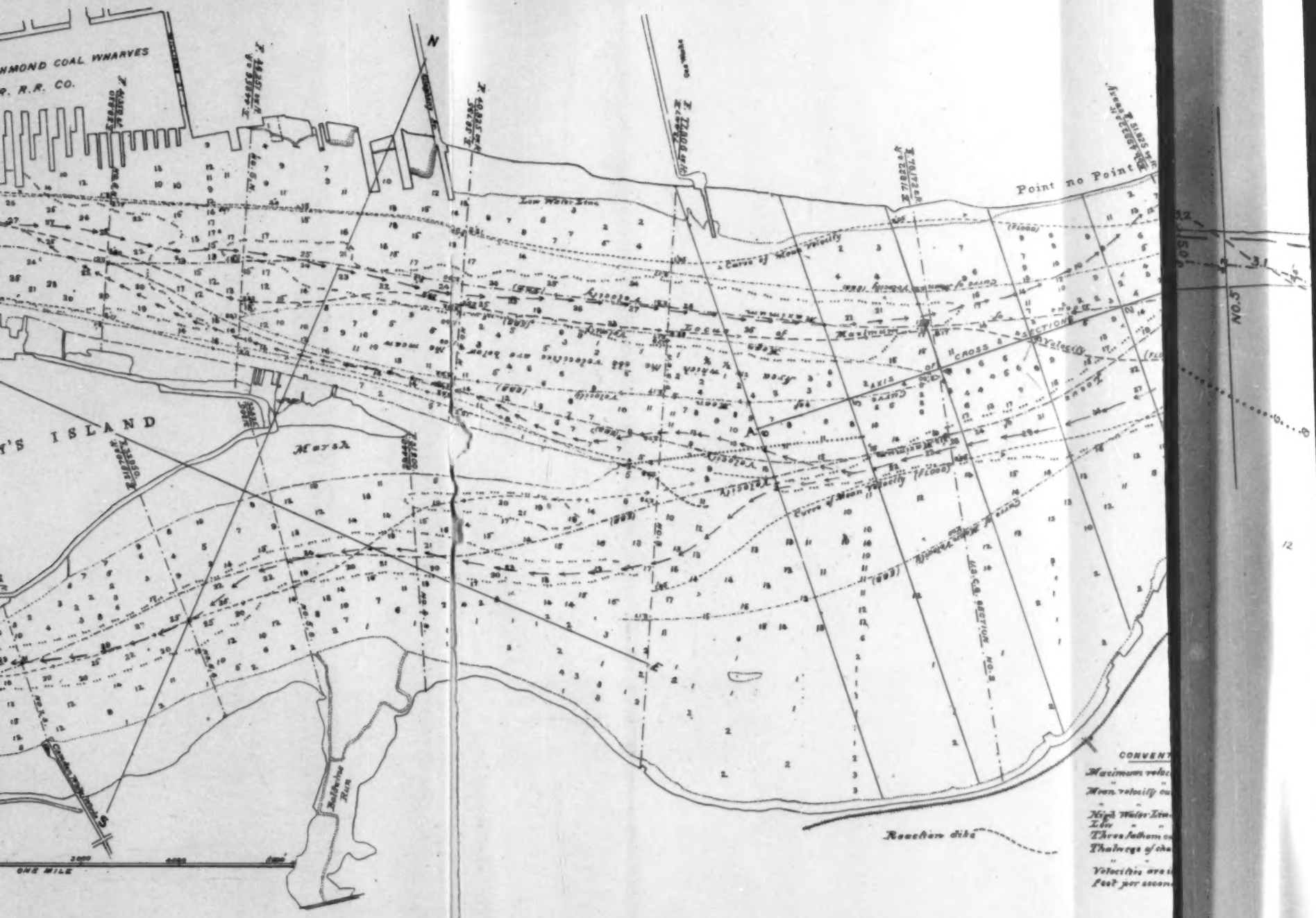
s Island, Philadelphia,
tive velocities and
provements.

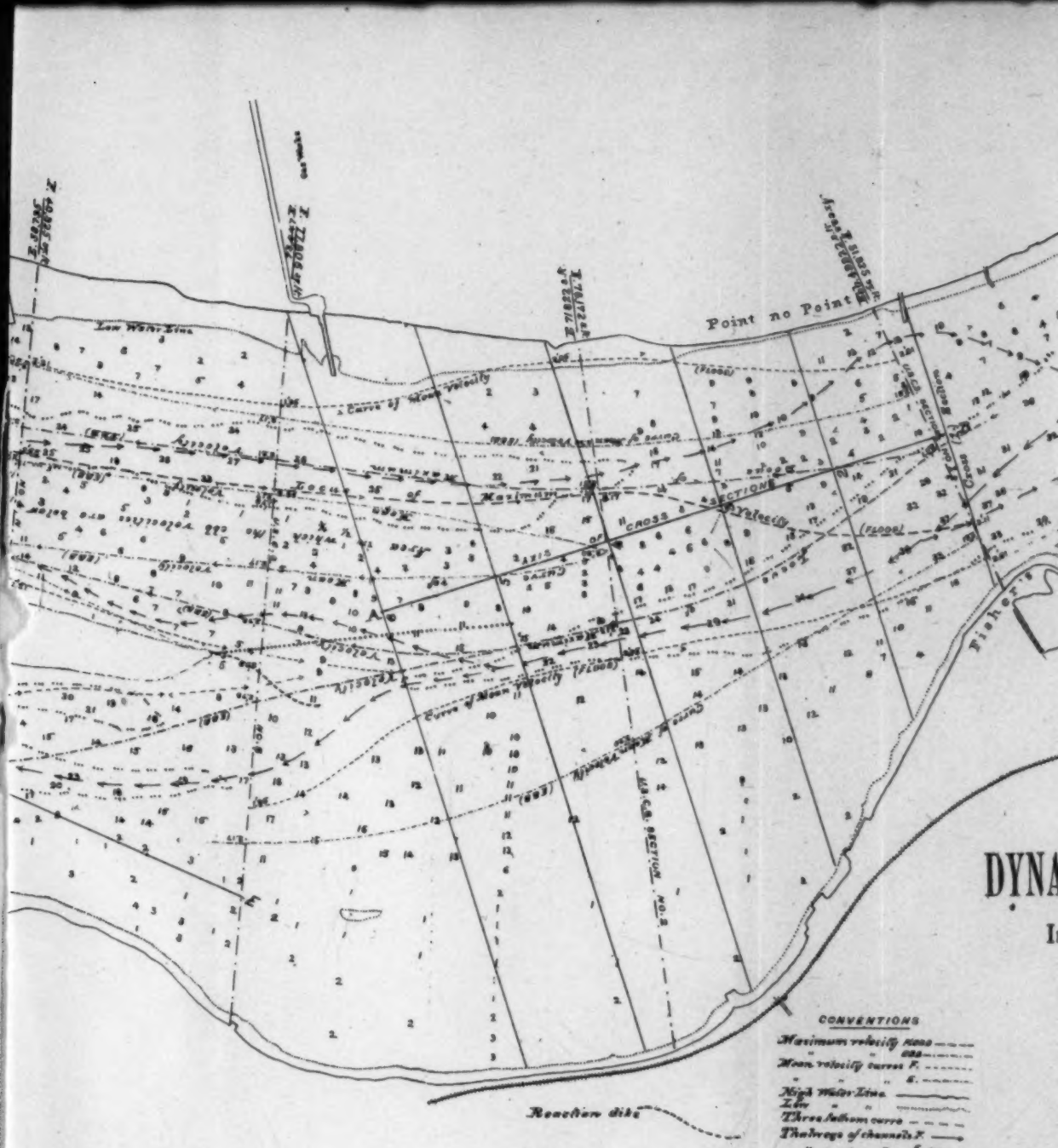
ED BY

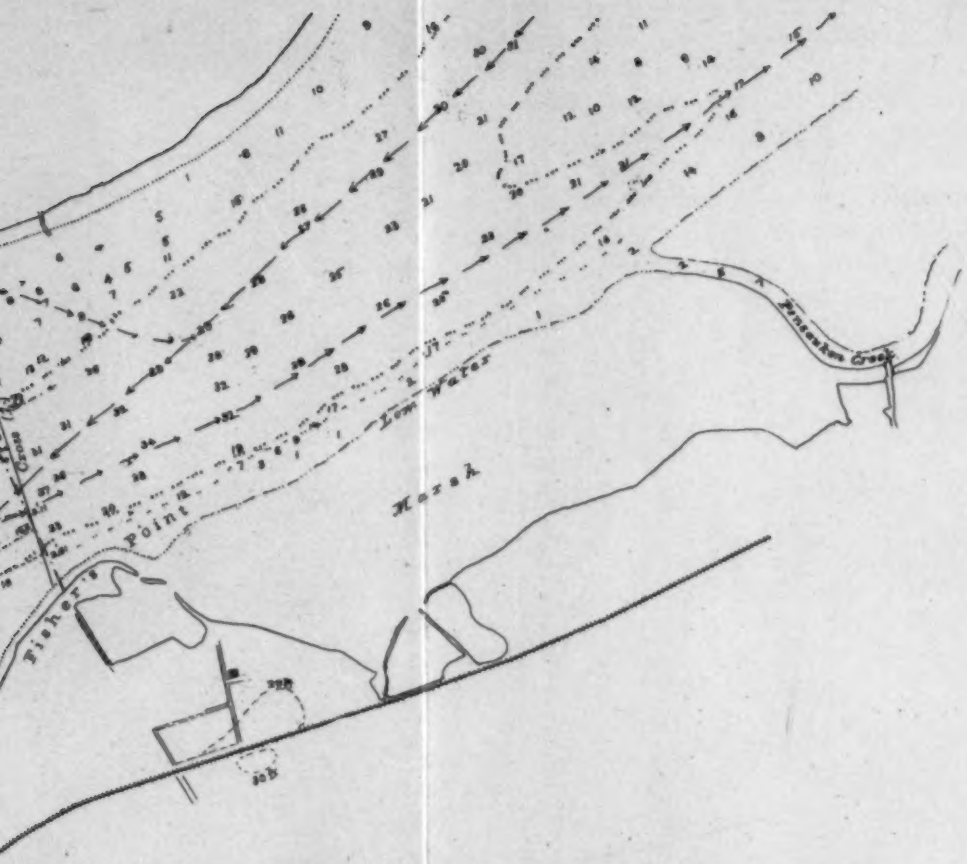
. HAUPT


PORT RICHMOND COAL
P. & R. R.R. CO.
PETTY'S IS
Cooper Creek
ONE MILE

Haupt.)


HMOND COAL WHARVES
Q. R. R. CO.
Point no Point
Low Water Line
Curve of Mean Velocity
Curve of Mean Velocity (Flood)
Mean Velocity
Velocity
Cross Axis of Cross Sections
Mean Velocity
Reaction dike
ONE MILE
NO.5


Point no Point
Low Water Line
Curve of Mean Velocity
Mean Velocity
Velocity
CROSS SECTIONS
AXIS
Curve of Mean Velocity (FLOOD)
Fish
Reaction dike
CONVENTIONS
Maximum velocity flood
Mean velocity current F.
High Water Line
Low
Three fathom curve
Thalwegs of channels F.
Velocities are indicated in feet per second.

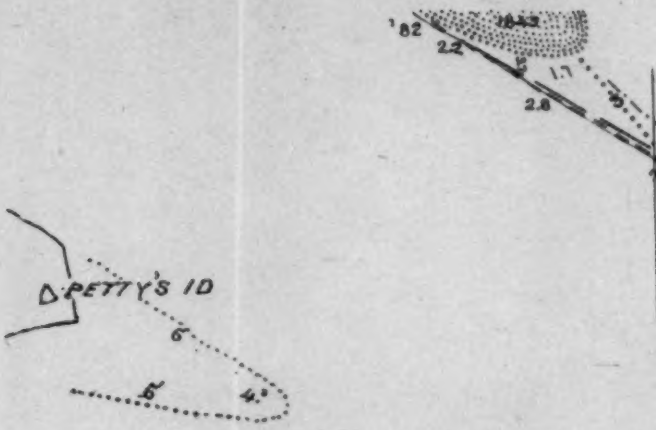


DYNAMIC CHART of the DELAWARE RIVER

In the vicinity of Petty's Island, Philadelphia, showing depths, relative velocities and proposed improvements.

COMPILED BY

LEWIS M. HAUPT



COMPARATIVE CHART

SHOWING CHANGES IN THE CREST

OF

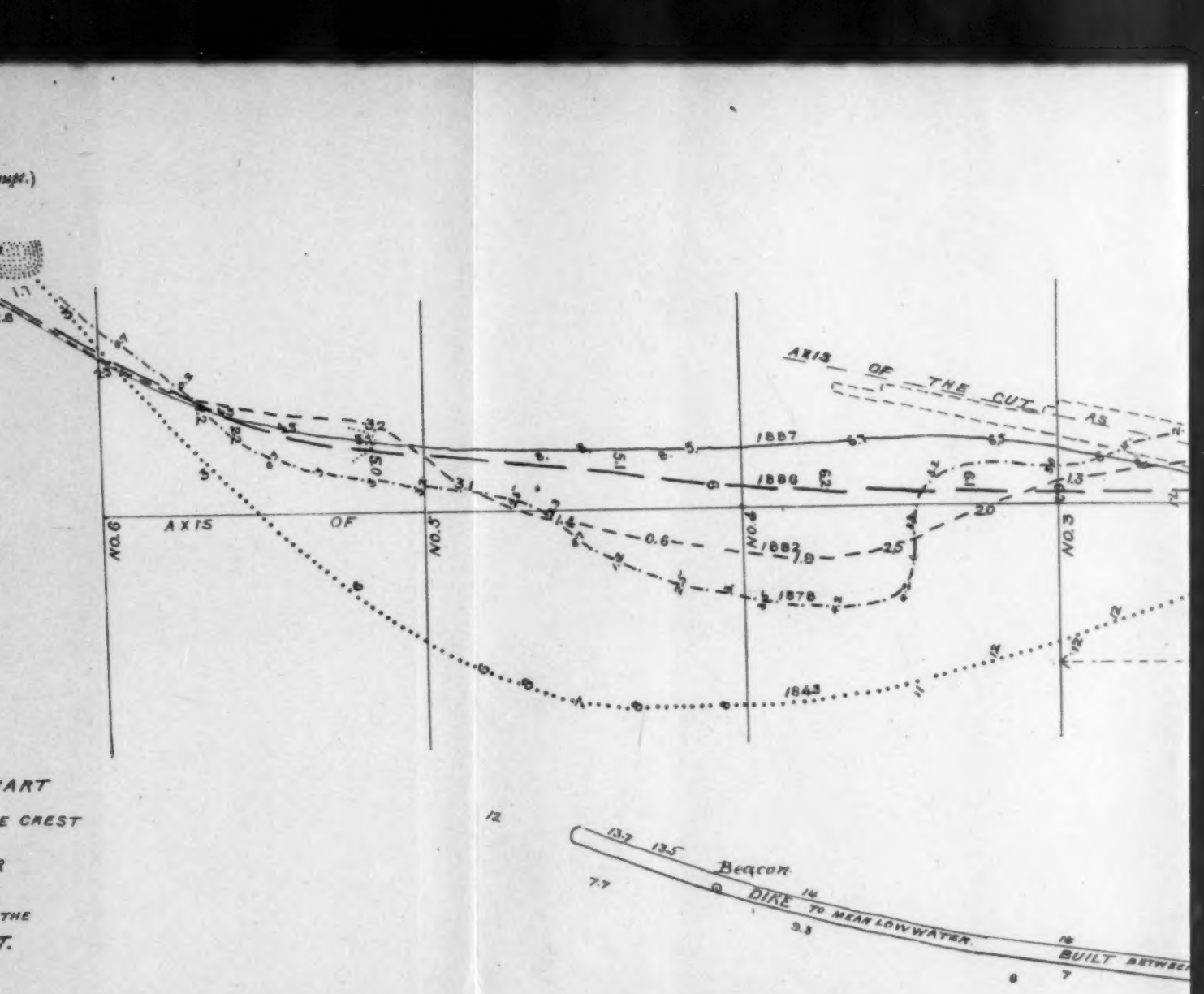
FIVE MILE BAR

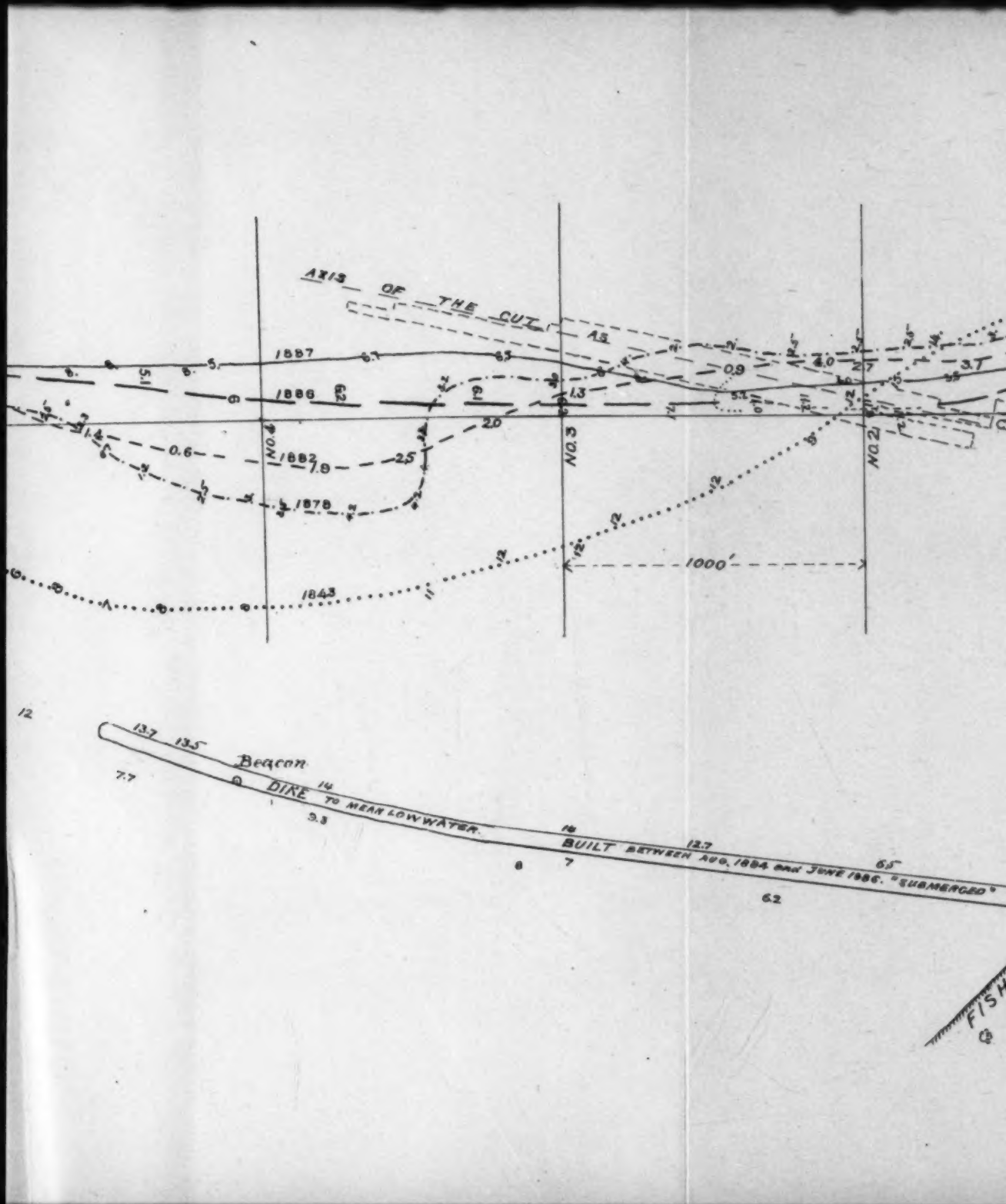
DELAWARE RIVER,

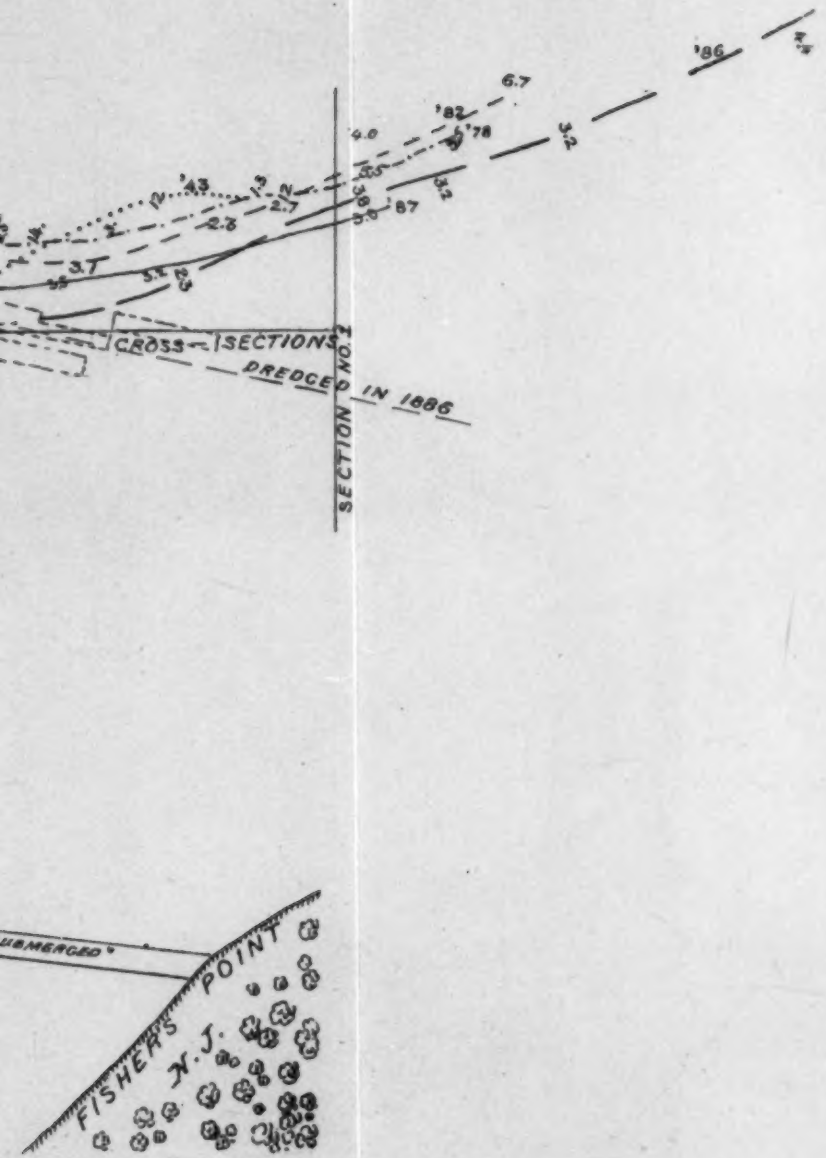
WITH THE POSITIONS OF THE

DIKE and the CUT.

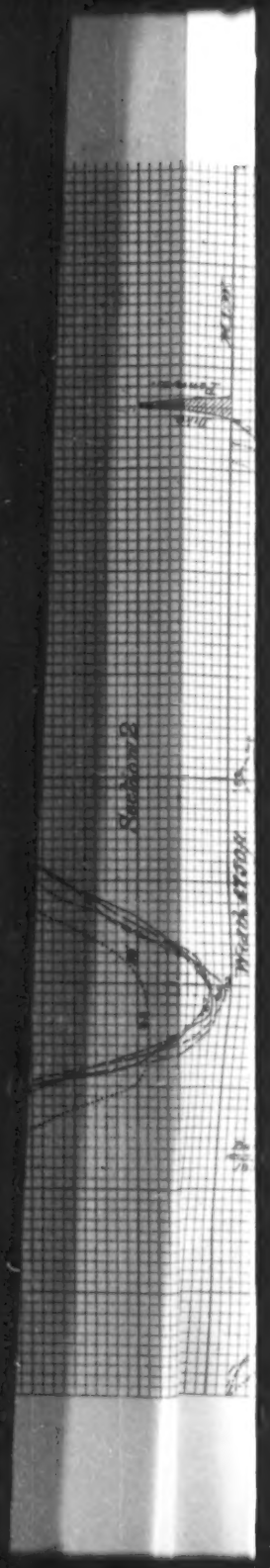
1886.

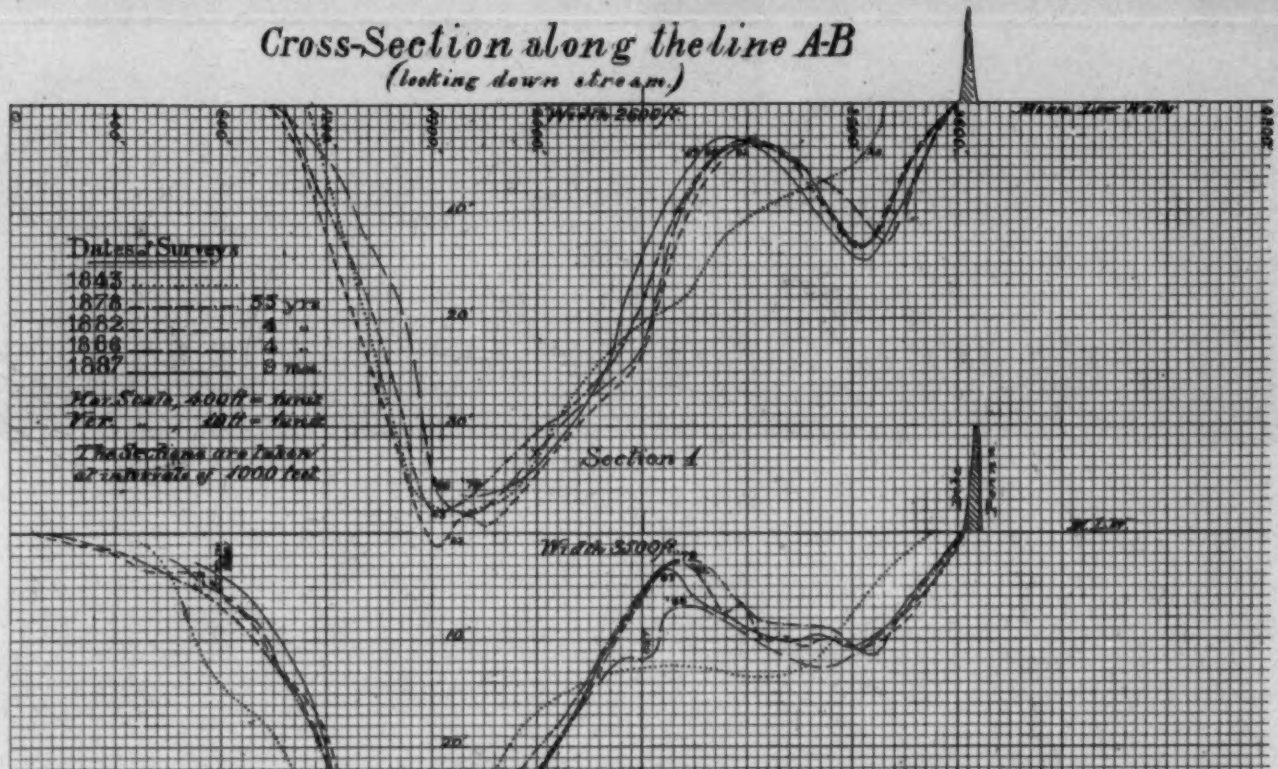

AXIS OF THE CUT
1887
1886
1882
1878
1843
AXIS OF
NO.6
NO.5
NO.4
NO.3
Beacon
DIKE TO MEAN LOW WATER.
BUILT BETWEEN

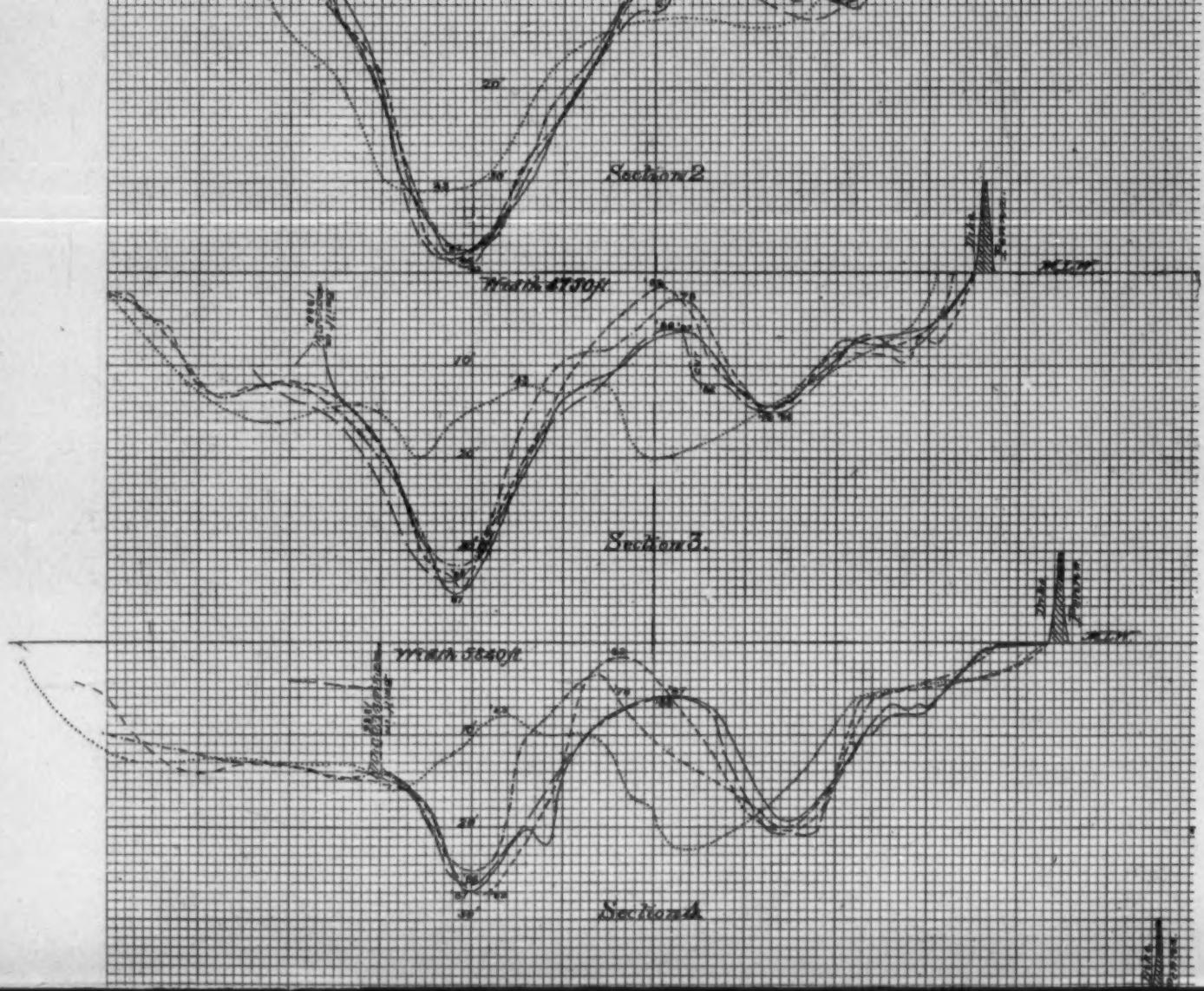

AXIS OF THE CUT AS
1887
1886
1882
1878
1843
NO.4
NO.3
NO.2
1000'
Beacon
DIKE TO MEAN LOW WATER.
BUILT BETWEEN AUG. 1884 and JUNE 1886. "SUBMERGED"
FISH

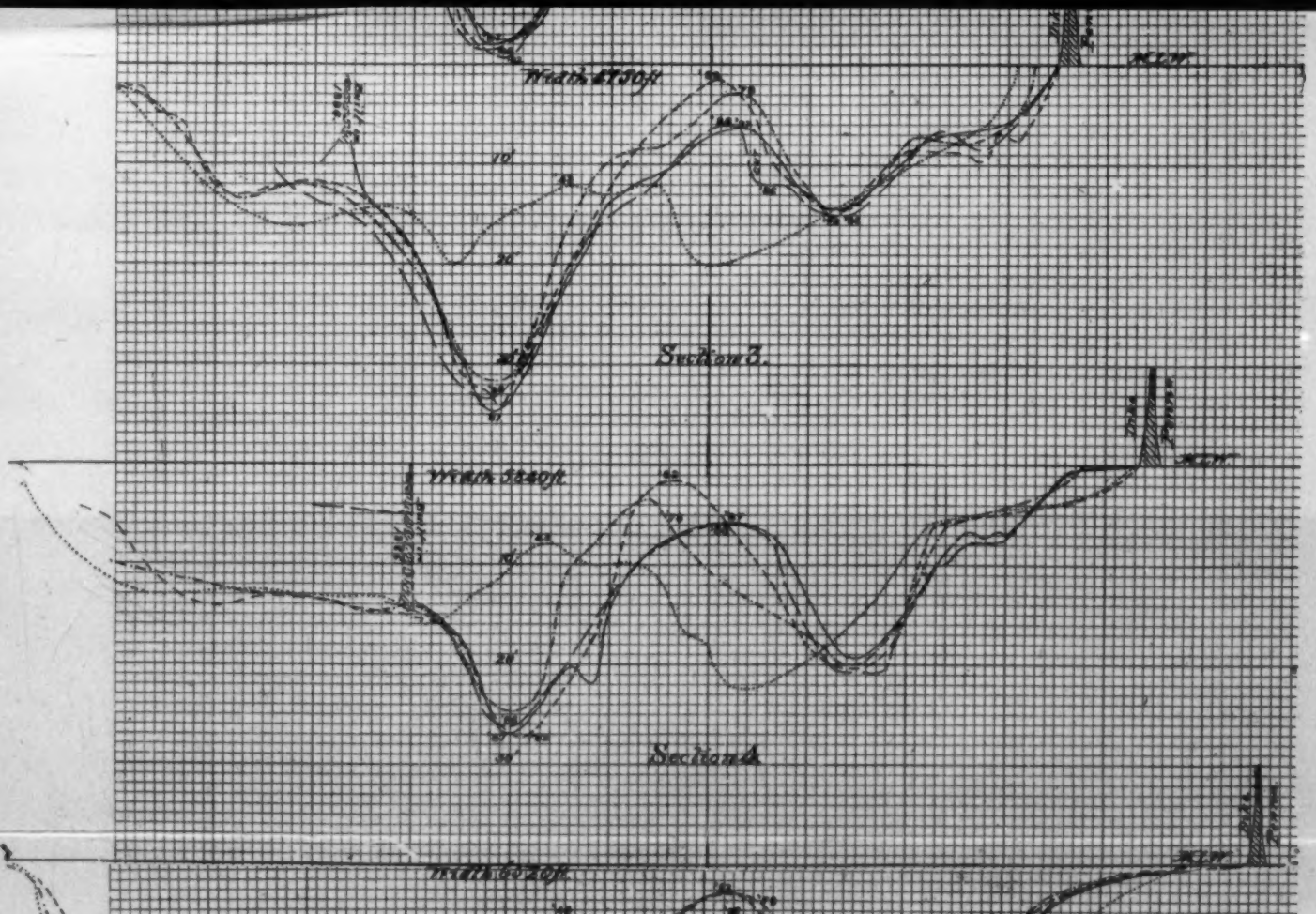

'86
6.7
'82
'78
4.0
3.2
'43
2.8
2.7
3.7
'87
CROSS SECTIONS
DREDGED IN 1886
SECTION NO. 2

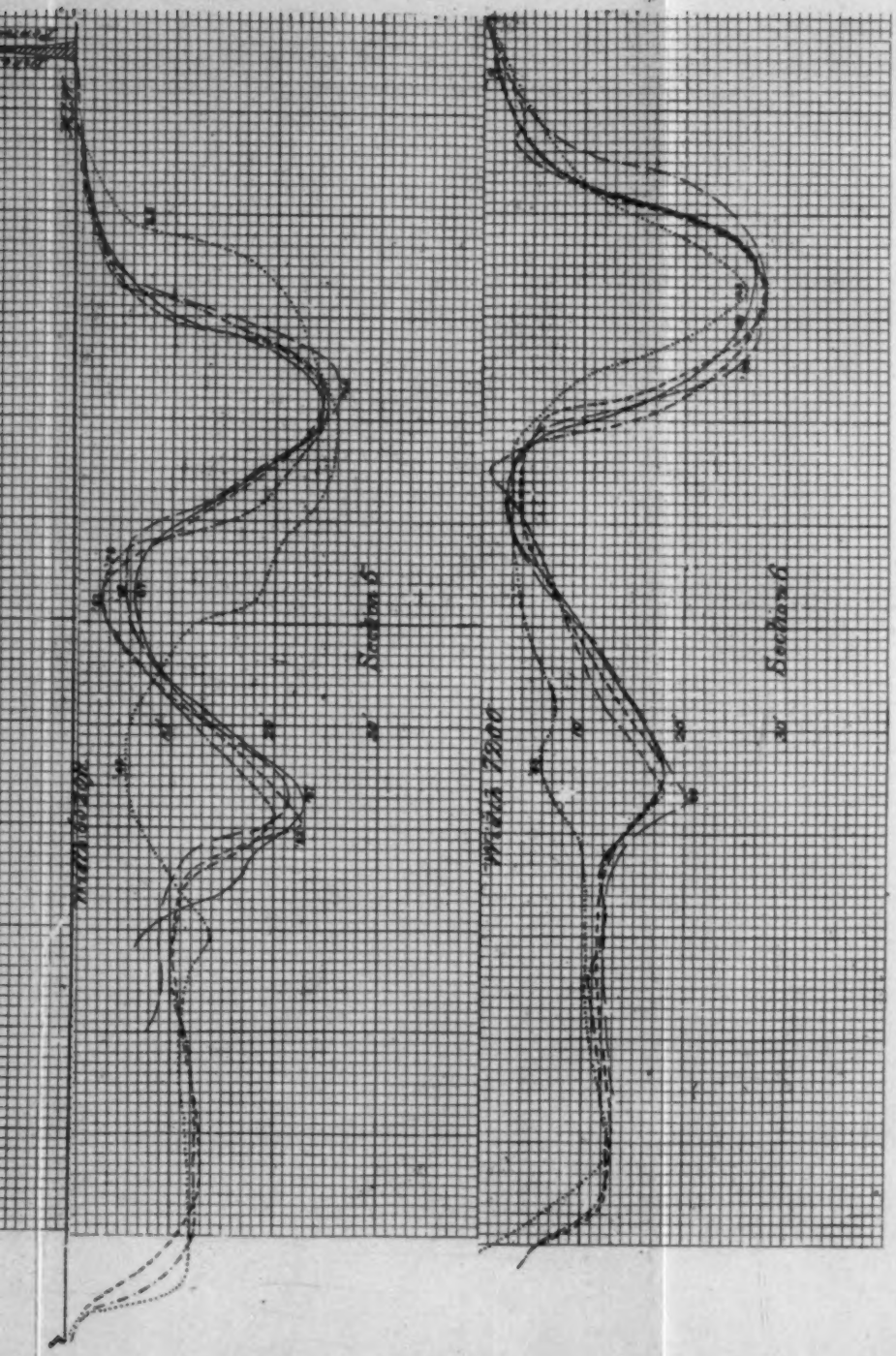
SUBMERGED
FISHERS POINT
N. J.

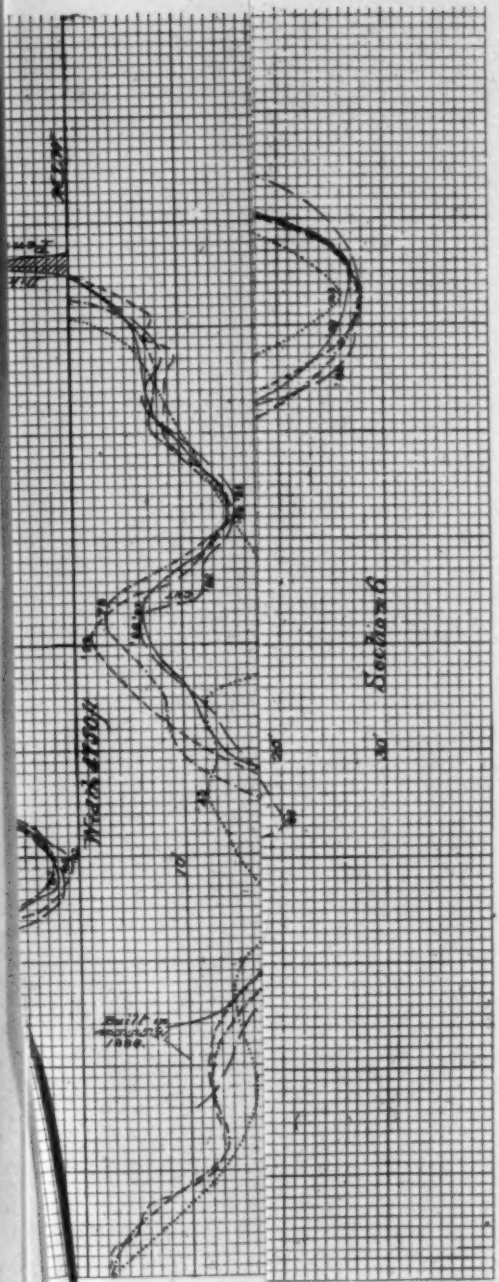



Cross-Section along the line A-B
(looking down stream.)
Width 2000ft.
Mean Low Water
Dates of Surveys
1843
1876 — 55 yrs
1882 — 4 "
1886 — 4 "
1887 — 2 mths.
Hor. Scale, 400ft = 1inch
Ver. 40ft = 1inch
The Sections are taken at intervals of 1000 feet
Section 1
Width 3200ft.
M.L.W.


Section 2
Section 3.
Section 4.


Section 3.
Section 4.


Section 5
Section 6


Stockton

distributing their effects over the whole section included between the dike and the opposite bank. The water is thus deflected laterally in horizontal planes and tends to scour away the *sides* of its bed, which are opposed to this contraction, but the increased resistance also raises the general level of the stream and so produces a velocity *head*, which is the effective force in scouring upon the *bottom*. It is the *additional* momentum, due to the resulting increased velocity, that produces the scouring upon the bottom, and this is relatively more effective near the sides of the stream than at the centre. It is moreover, evident, from the observed velocities, that there is a mean current over the bar amply sufficient to remove any material in that vicinity; and yet the bar remains, because of the equilibrium between the flood and ebb movements, and because the bottom velocities are but feeble as compared with those on the surface.

The whole problem, as it presented itself to me, so far as the urgent and immediate needs of commerce were concerned, required the removal only of a *sufficient amount* of material from the crest of the bar to afford a passage for vessels drawing less than twelve feet of water, and *not the removal or disturbance of the entire bar*. This result, I believed, could be accomplished in one of two ways, both of which are local and direct in their application and neither of which can be injurious to the other parts of the river.

The methods both embody the principle of the utilization of the surface currents, either by a vertical deflection or by reaction, in combination with a lateral compression and concentration of a portion of the ebb and dispersion of the flood thus producing a greater *difference* in the amount of the flood and ebb movements of the particles than exists in a natural or unimproved condition.

The means taken to effect these changes are quite different; the one, being of a movable and temporary character, the other, permanent.

The first consists of a series of wings or gates, which swing about a horizontal axis at or near the surface of the water. The gates are hinged to caissons, scows, or any suitable floats which may be anchored in any position and at any angle to the currents. The gates are also ballasted to any extent dependent upon the pressure due to the velocity, and are left to do their work. As it was doubted whether or not the water would pass under, rather than

around, the ends, and as it was desired to have the data from actual experience, without any conjectures, arrangements were made to test the efficacy of this principle on the crest of Five Mile Bar, where the dam would not obstruct navigation, and accordingly a limited company was organized and a plant erected during July of this year (1887).

EXPERIMENTS WITH CURRENT DEFLECTORS AT FIVE MILE BAR.

Two wings were put in position, the left one on the south side being 140 feet long and containing seven gates; the right wing 100 feet long with five gates, and leaving a channel way between them of 135 feet. The axes of the wings made an angle of 135°, that is, an intersection angle of 45° for the purpose of increasing the ebb prism through the channel.

The gates were twelve feet in depth, and were suspended so that at low water the lower edge was about eight feet below the surface.

Each gate was loaded with about 1,600 pounds of ballast, and, as a matter of economy, the supports were made of pile bents (as shown in the side elevation *Fig. 2*) instead of floats for this experiment. The deflectors scoured out a depth about equal to the distance from half tide to their lower edges, and increased the original depth from its average of nine to eighteen and twenty feet. This was more than I had anticipated, as it was only at the stand of the tide that they hung vertically, and I was still more surprised at the rapidity of their execution. Scarcely were they launched before the action began on the bottom, and within a few tides their immediate work was done. What the indirect effect will be upon the channel between the wings remains to be determined, as it is a question of time. Theoretically, the material from these elliptical basins would be deposited in mounds on either flank, which should aid in trailing the ebb, whilst the bottom material in the channel, being left somewhat unsupported, should gradually flow off laterally, and be carried to the mounds. The experiment confirms the supposition that such a floating plant would make an excellent current dredge, where there are sufficiently deep pools into which the dislodged material might settle without injury, as frequently occurs.*

* These devices are secured by Letters-Patent No. 339,548, issued April 6 1886.

The other or permanent device is what I have called a *reaction dike*, and is intended to be an aid to navigation, being both a day and night beacon, as well as a means for deepening and improving channels. It is, briefly, a permanent structure of such *form* as to

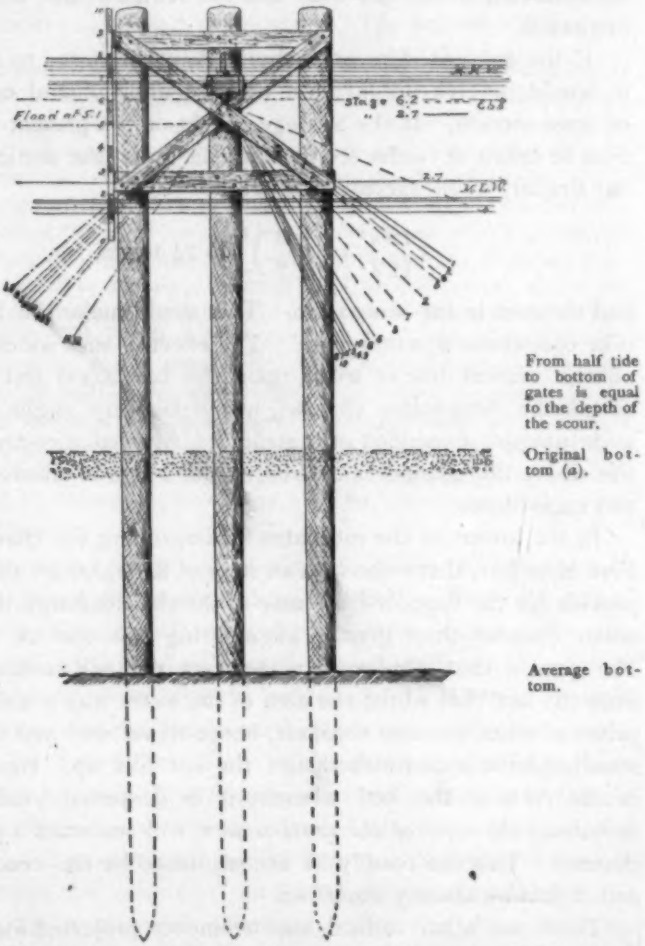


FIG. 2. Section Showing Position of Gates at Different Stages of the Tide.

catch, compress, deflect and train a sufficiently large prism of the ebb to give the required depth which is obtained by producing a reaction of the mid-stream velocities upon the bottom. It is so placed, also, as to defend the channel from the deposits carried up

by the flood and thus increase the differential movements between these opposing currents. Its length will be about 1,000 feet, which is much less than that of the ordinary in-shore dike, and its effects much greater on the particular part of the obstruction to be removed, hence the cost will be reduced and the efficiency increased.

If the present dike at Fisher's Point be raised to high water, it would involve an increase of base and general enlargement of cross-section. If the average height of the present submerged dike be taken at twelve feet, to add six more, the sections remaining similar, would increase the area

$$\left(\frac{18}{12}\right)^2 = \left(\frac{3}{2}\right)^2 = 2\tfrac{1}{4} \text{ times,}$$

and the cost in the same ratio. This would make the high water dike cost about $50,000 more. The effect of such an enlargement on the present line of work, upon the bar 2,000 feet away, and across the deep-water channel, would be very slight, whilst the same amount expended on a structure situated directly upon the site where the channel is desired, would be more effective, definite and expeditious.

In the lowest of the estimates for improving the channel across Five Mile Bar, there was also an item of $462,000 for dredging, to provide for the supposed increase of the ebb discharge through the north channel, thus greatly augmenting the cost of the work. The reason that dredged channels are not self-sustaining arises from the fact that whilst the area of the water way is enlarged, the prism of water remains constant, hence its velocity and consequent scouring force is diminished and the cut fills up. But a *change in the form* of the bed whereby it is deepened, locally *without increasing the area of the cross-section*, will maintain a permanent channel. This can readily be accomplished by the reaction-dikes and deflectors already described.

There are other radical improvements projected for this port, which involve a very large expenditure, but the length of this paper prevents their consideration for the present.

University of Pennsylvania.
Philadelphia, September 21, 1887.

SUPPLEMENT.

After the above-named paper was completed, there was handed me a printed description of the plans suggested by the Advisory Commission, as read at their meeting, held May 8, 1883. As this is authentic and explicit, I have appended it as a part of the history of the studies as to this part of the river. The record reads:

"After studies of the probable effect of deflecting works at and below Fisher's Point without satisfaction, because of the difficulty of accommodating such works to both ebb and flood, it is proposed *to extend the eastern point of Petty's Island*, not only over the ground lost since 1843, but beyond, so as to control the proportion of the ebb which shall seek the channels below. The crude conception of the work is a dike of fascines or cribs extended *in a straight line towards the extremity of Fisher's Point or to the left of same*, so as to leave about the same sectional area on either side, as things are now. This dike would fall to southward of the split of the ebb current, and to the *southward of the line of* MID-VOLUME, so that it would induce a greater proportion of flow to the northward of Petty's Island during ebb, without disturbing the relations of flood volumes, or injuriously affecting the canalized southern channel; indeed, this dike would form a part of the project for the south channel, and to its advantage, since it would probably arrest the shift of deposits which, since 1843, have caused the thirteen and one-half feet channel to wander among the shoals, and may, possibly, increase the channel depth. *It would not be less than 2,600 feet long beyond the low water point of the island.*"

The extents and locations are stated in the parts I have italicized. The object is "to control the proportion of the ebb which shall seek the channels below" and "induce a greater proportion of flow to the northward of Petty's Island during ebb, without disturbing the relations of flood volumes." It will thus be seen that the conclusions reached in the body of my communication as to the site for and object of the works are identical with those stated by the Advisory Commission more than four years earlier, yet the plans which have been executed are those to which the Advisory Board gave but a qualified approval, based upon hope of success. As to the *means* of producing the desired effects, there appears to be a material difference, for if the dike as above described, be plotted as shown on *Plate II*, by the heavy dots extending 2,600 feet from low water at the eastern end of the island in a straight line to the extremity of Fisher's Point, it will not leave the curve of mid-volumes to the north of it, but will intersect it a short distance from the island and leave it on the

south, so that the area and volume of the ebb section and prism on the north side will be diminished and the proportion of the ebb stream flowing in the *south* channel would be increased, to the further detriment of that on the north side.

The *reaction dike* (*Plate II*) jutting out from the head of the island would have a development of but little more than one-third the length of the straight one, and would withdraw a prism discharging about 15,000 cubic feet per second, or more, if it be found necessary, from the south and project it into the north channel, thus increasing the ebb velocity of the portion near Petty's Island to over three feet per second, and giving a straight channel of sufficient magnitude to satisfy all the present requirements of commerce. By extending the dike, future demands may readily be met by the same means.

University of Pennsylvania, October 7, 1887.

DESCRIPTION OF AN IMPROVED TRIPLE-EXPANSION ENGINE.

By Wm. M. Henderson.

[*Read at the Stated Meeting of the* Institute, *held Wednesday Sept. 21, 1887.*]

Mr. President, Ladies and Gentlemen:—The latest innovation in steam engineering has been the introduction of triple-expansion engines. About the year 1863, being then in the South Pacific, I remember what a furore was cerated by some new steamships sent out from the Clyde by Messrs. Randolf, Elder & Co., having compound or double-expansion engines, which effected a saving in fuel of about twenty-five per cent. over the existing single-cylinder engines; notwithstanding the fact that the engines in use were fitted with approved expansion gear. These compound engines, as most of you are aware, had two cylinders; the second cylinder being about twice the diameter of the first. Engineers of eminence are not wanting who still insist that all the advantages of the compound engine can be secured in the single cylinder type, provided the total ratio of expansion in the two engines is the same. Facts prove this not to be the case, to which my single cylinder friends reply, "So much the worse for the facts."

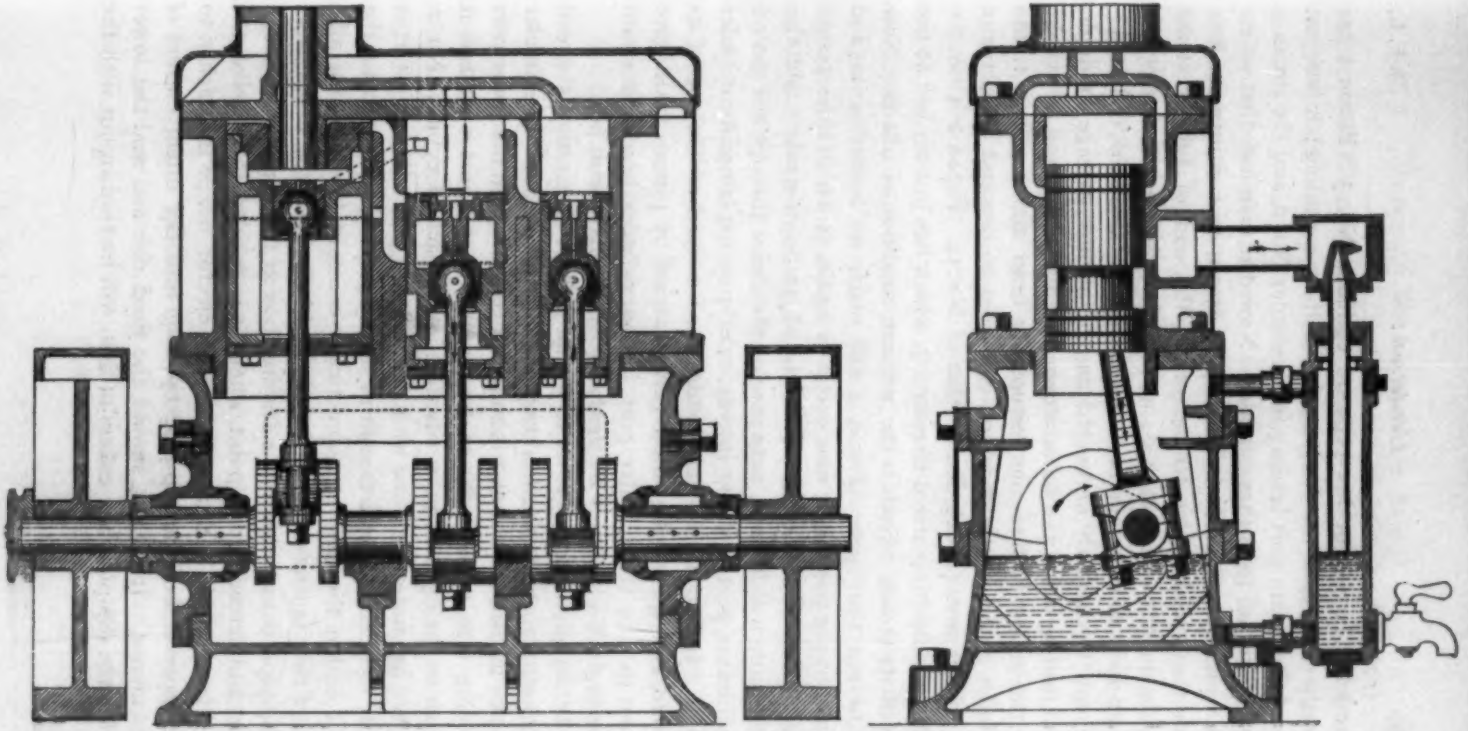
The compound engine reigned supreme for about twenty years, when another mechanical departure took place in the production of the triple-expansion engine, which overcame the double-cylinder engine to the same extent that the double had surpassed the single-cylinder engine. Another advance of twenty-five per cent. in the economy of fuel. These are facts reiterated in every mechanical journal of the day. To endeavor to explain the causes bringing about this result would occupy too much time at this meeting. But it may all be accounted for in using higher pressure and causing the work of the steam to be performed in separate cylinders, where the difference of the initial and the final temperature in each is divided into gradual stages; and not compelling the extremes of temperature to occur in the same cylinder, where the refrigerating effect of the walls, left cold by the exhausting steam, meets the hot supply, fresh from the boiler, producing sudden condensation to the fullest extent. With this brief introduction, I will now pass to the object of my remarks—a triple-expansion engine possessing, I believe, in a marked degree the valuable characteristics found in our latest achievements in engines pertaining to the merchant marine, with the humblest means, fitted to perform the duties of domestic work with the same fidelity and contributory economy as developed in our fastest ocean steamships. This result, however, was not accomplished at once. I had to grope my way, step by step; and it took me over two years of constant study and experimenting, to produce the engine now thrown upon the screen.

In this engine I have succeeded in doing away with all receivers, steam jackets and the valve motion entire. There are no valves, eccentrics, piston, valve, nor eccentric rods, nor any cross-head pins, stuffing boxes, packing rings, nor cut-off gear; and yet the engine is of full piston type, and expands the steam five times. I believe that it possesses a greater degree of simplicity and endurance than even the common slide-valve engine can boast of.

There are three single-acting cylinders, 1, 2, 3, mounted on a crank case. No. 2 is twice the area of No. 1, No. 3 is twice the area of No. 2, and four times the area of No. 1. The pistons perform all the functions of the valves usually employed, passing the steam successively from one cylinder to the other throughout the series, receiving it at ninety pounds pressure, cutting off at two-

thirds stroke in the first cylinder, and exhausting it at about four pounds from the last. In the modern triple-expansion engine, three unequal pistons are used, and three unequal piston valves. Now, please observe the three pistons in this engine. They may be viewed as pistons of the trunk variety, and they are, to all intents and purposes, piston valves as such are made. By coincidence, each occupies the correct relative position as a valve for its neighbor, as nearly as could be desired. The three-throw crank, operated by the pistons having the property of admitting the steam at the commencement of the stroke and cutting off at three-fourths stroke on the piston next following in rotation, all we have to do is to form steam ports leading from cylinder No. 1 to the upper end of cylinder No. 2, and from cylinder No. 2 to cylinder No. 3. The pistons, then, without losing their original identity, become transformed into piston valves governing the operations of the adjacent cylinders. For convenience, a departure is made in the case of the low pressure piston, which is made to carry a piston valve attached to its head, one-half the diameter of the high pressure piston for admitting the steam to the leading or high pressure cylinder. The area presented by this valve being invariably subjected to the pressure of the initial steam, has three advantages: (1.) It tends to equalize the pressure on the pistons by reducing the effective area of the high pressure piston, the more powerful, and assisting the low pressure piston, the less powerful. (2.) It steadies piston 3 on its up-stroke, by providing a certain constant thrust found necessary for running at high speed. (3.) It is further valuable in relieving the engine from dead points, for should the engine stop with the head of the piston valve above the circular port, excluding the steam from the leading cylinder, the first action of the steam admitted by the steam valve will be to push the piston valve down, admitting the steam to the first cylinder. This, in its descent, will pass it to the intermediate cylinder, and from here it will be transmitted to the last of the series, causing the engine to revolve. In any other position, where the circular port is uncovered by the valve, the engine will start, because the steam will then be properly admitted.

Perhaps the simplest way to describe the action of this engine will be to take it just where the pistons are represented; calling the smallest or high pressure cylinder No. 1, the intermediate No.



HENDERSON'S TRIPLE EXPANSION ENGINE.

2, and the largest or low-pressure cylinder No. 3. Piston 1 has already completed its down-stroke, and is ascending; it has just closed the steam port leading into cylinder No. 2, and the steam is thereby cut off from that cylinder. Now it is manifest that unless some provision is made to permit the steam to continue its flow from the one cylinder to the other, the end of further steam expansion has been reached; as the compression above piston 1 would soon stall the engine. But piston 2, at this time, is descending, and has already uncovered an equilibrium passage (in duplicate) leading out of the initial steam port above, opening an avenue for the steam to flow uninterruptedly from above piston 1 into cylinder 2, the piston of which continues to descend by virtue of its greater area (about double that of No. 1). Piston 2 is on the point of admitting steam to piston 3, which has just arrived at the top of its stroke. Such is the present condition of affairs. Now follow out the cycle. Piston 2 will reach its lowest point, and return to the position it now occupies again, at which time piston 3 will have descended three-fourths of its down-stroke; and the same thing will happen, as to passing the steam through the second equilibrium port, opening into cylinder 3, as explained for cylinder No. 2. Just at this point, piston 1 has arrived at the top of its stroke, and the small piston valve carried by piston 3 will give steam to it by the circular port in the cylinder head, the steam entering cylinder No. 1 by the horizontal initial steam port.

When piston 3 descends to within a short distance of the end of its stroke, the exhaust takes place with a fair lead. The circular groove formed on piston 2 is timed to coincide with the lower port opening into cylinder No. 2, to receive the exhaust and pass it across to the exhaust pipe, situated on the back of cylinder No. 2.

We are not quite done with that exhaust yet. Its last effort is made to free the crank case from heated vapors, and maintain the fluid within the case at a practically constant level. A metallic gauge tube is connected to the top and bottom of the crank case, a dip-pipe passes through a stuffing box at the top of the gauge tube, and descends to a point where it is decided to establish the fluid level within the case. A small ejector nozzle is attached to the upper end of the dip-pipe opening into the direct current of the exhaust. It is clear, should the fluid rise and seal the lower end of the dip-pipe, any excess of fluid will be thrown out with the

exhaust. At all other times the outward blast of the exhaust will free the crank case from heated vapors and keep it in a cool condition.

Having now given a brief outline of the manner in which this engine works, I must, for the benefit of those who are critically inclined, explain some of the novel points introduced whereby I bring about the advanced results.

First.—We have the balanced triangular crank shaft, the pin centres of which are 120° apart. It is truly balanced; because the centre of motion coincides with the centre of gravity, just as a disc-crank would be; but it possesses the double advantage of being lighter and more readily got into working position.

Second.—At the bottom of each trunk piston a cover plate is attached, slotted to allow only the vibration of the connecting rod. The object of this is to prevent that splashing of the contents of the case into the interior of the hollow pistons, to lubricate the cross-head pins, which occurs in all engines of this class; converting each hollow piston into a species of *surface condenser*, not only wasting the working steam by unnecessary condensation, but also unduly heating the lubricant, and thereby the journals. You can not bear your hand upon the crank case of any engine now built. It will seem strange to have a high speed engine running with cool bearings and a cold crank case.

Third.—I would briefly draw attention to these hollow heads with removable sleeves, affording constant lubrication of the shaft journals entirely from within the case; and the continuous lubrication of the upper joints of connecting rods from above, by steam condensed there, mixed with whatever lubricant is used on the pistons. The ball and socket joint is worthy of a little consideration. We all know how difficult it is to secure a cross-head pin in that situation, precisely parallel to the driving crank pin. No binding here!

Fourth.—The direct delivery of the steam from one cylinder to the other throughout the series, by the movement of the pistons themselves without valves or receivers, is the dominant feature of the whole.

There remains yet one little thing to describe, without which this engine is of small account. You will notice there are several ports piercing the bore of the cylinders. Take this one, for

instance; say that it is ½ inch wide by 2 inches in length, representing an area of one square inch. Suppose the steam to be 100 pounds pressure, we should have 100 pounds of force jamming the piston over to the other side of the cylinder, producing, in the first case, excessive friction, and in the second, opening an avenue for the steam to escape past the piston. To overcome all this, I simply cast a shallow impression of each port opposite to it, and lead thereto a small semi-circular duct. Now equilibrium of pressure is restored, and the piston is freed from all side thrust.

The form of connecting rod is such as to permit the taking up of any lost motion; the same can be done in regard to the sleeves on the journals. But, it will be observed, the thrust is always in a downward direction, and that even with loose boxes the engine will not rattle.

In regard to the provisions to insure the down thrust, piston No. 1 has always the back pressure from cylinder No. 2 on it. In cylinder No. 2, the piston near the end of its up-stroke passes over the mouth of the second equilibrium passage leading to cylinder No. 3, and cushions on vapor entrapped there for the purpose of compression. In cylinder No. 3, we have the constant pressure of the initial steam upon the area of the piston valve.

All the pistons and piston valve are very long, being twice the length of the stroke, and are provided with water-groove packing, which I prefer in this construction of engine to any other. But any kind of piston packing can be used.

There are many other points I could enlarge upon, but time will not permit. I will, therefore, conclude, praying you to remember that "the greatest discoveries ever made in the world have been made by putting this and that together."

DISCUSSION.

MR. FULLERTON.—"What is the nature of the end boxes on the crank shaft?"

MR. HENDERSON.—"They are removable sleeves of phosphor-bronze, pressed into the cast-iron heads. The bearing is tapering one-sixteenth inch to the inch, wear may be taken up by the use of liners following up the taper."

MR. FULLERTON.—"How are they oiled?"

MR. HENDERSON.—"The crank case contains the lubricant. The boss on the cast-iron head is swelled, leaving a cavity when the sleeve is in place. Into this space lamp-wick is introduced through holes opening into the crank case. The lubricating fluid is led by other small holes, drilled through the sleeves, directly to the journals. Constant lubrication is thus maintained entirely from within the case. There are no oil-cups outside. The engineer has nothing to do with oiling the bearings, or, indeed, any part of the engine. It takes care of itself."

MR. FULLERTON.—"Have the two bearings between the central and the outer cranks any caps? or are they merely spring bearings?"

MR. HENDERSON.—"Merely spring bearings. There being no upward strain no caps are needed. These bearings are of Babbitt metal, run when the shaft, or a substitute for it, is in position."

MR. CHAMBERS.—"To what pressure is the steam cushioned in cylinder?"

MR. HENDERSON.—"That would vary under different circumstances, but I would say between one-half and two-thirds of the initial pressure."

MR. CHAMBERS.—"I have had engines running with very good results, cushioned up to boiler pressure. I would ask if the balance in the crank shaft balances the cranks only? or whether it balances the cranks, pistons and connecting rods?"

MR. HENDERSON.—"The crank-shaft is balanced. All, except the crank pin; that, together with the weight of the piston and connecting rod, is balanced by counter-weights in the balance wheels; not by placing a counter-weight on the wheel opposite the weight to be balanced, but by coring out of the rim a corresponding mass on the same side as the weight which is virtually the same in effect, and does not interfere with turning the wheel up in a lathe.

MR. CHAMBERS.—"Then you have a standing balance and not a running balance?"

MR. HENDERSON.—"Each piston and connecting parts are balanced by counter-weights in the rims of the balance wheels, halved between the two, allowing for the difference of leverage

between the distance of the crank-pin centres, and the centres of gravity of the weight in the rim from the centre of revolution. The engine is balanced standing, and is also balanced running, as far as the weights of the pistons, etc., are concerned. The influence of the varying steam pressure is not so easily balanced by a fixed weight. But I have found that if the running parts of the engine is balanced, that is near enough for all practical purposes. The momentum due to steam impulse, is thrown into the balance wheels assisting the pistons to make the return stroke. The excess may be taken up by a properly calculated back pressure on each individual piston."

MR. J. H. COOPER.—"Are the cranks 120° apart?"

MR. HENDERSON.—"Yes! They are arranged equi-distant around he circumference of the crank-orbit."

MR. COOPER.—"The upper ends of the connecting rods appear to be jointed to the pistons by spherical bearings. Do these wear well in practice? In some situations such bearings wear very unequally."

MR. HENDERSON.—"The question of wear being simply one of surfacef, if I can give the same wearing area to a ball, that I can to a cross-head pin, the wear will be the same. The ball-joints in these engines have about double the wearing surface, usually given to cross-head pins in engines of this class. When it is considered that both the joint and piston are relieved from all binding strain, the wear is necessarily reduced. How well this kind of a joint wears can be estimated from the fact the Brotherhood three-cylinder engine has been running with this kind of a joint about fourteen years, and they are building them that way yet."

MR. COOPER.—"Is the exhaust steam condensed in this engine, and is vacuum made available in the third cylinder?"

MR. HENDERSON.—"The steam is not condensed, nor is a vacuum available, I think, in the third cylinder. To do this, I should have to go back to the triple-expansion engine as now built. All has been successfully accomplished. My engine is a departure from it, dropping the condenser, the receiver, the valve motion, and all the complication there existing. It is intended for domestic purposes, where from six to about 100 horse-powers are wanted."

MR. COOPER.—"Is that an ejector in the exhaust pipe, with pipe dropping into the shaft cistern, and what purpose does it serve?"

MR. HENDERSON.—"That is a small ejector operated by the final effort of the exhausting steam. Should the fluid rise in the crank case above where it is wanted, it will also rise in the dip pipe well, and seal the mouth of the dip-pipe, and be thrown out with the exhaust. At all other times the blast of the exhaust across the ejector will free the crank case from heated vapors and maintain it in a cool condition. Up to this time all the crank-case engines are running with cases heated up above 212°. The crank case in this engine will be cold."

MR. COOPER.—"Allow me to thank Mr. Henderson for the care he has taken in the preparation of the paper and drawings illustrating his new engine, and for presenting them so clearly for the benefit of members of the INSTITUTE."

LOSS OF HEAD IN HYDRAULICS.

BY IRVING P. CHURCH, C.E.

It is the purpose of the present article to offer some comment on Mr. Frizell's paper, in the October number, 1886, entitled "Coefficient of Efflux from an Orifice Furnished with a Short Pipe," in which there seem to be evidences of misconception, or at least a very unusual view, of a fundamental point in hydraulics, viz., "loss of head." It is true that the final result in Mr. Frizell's paper is correct, but the error as to "loss of head" in the first part of his work, is annulled by the subsequent introduction of what, from his standpoint, must be regarded as a "gain of head," an idea which, in the case under treatment, would controvert the principle of the conservation of energy.

Mr. Frizell seems to proceed on the supposition that a loss of velocity $\left(\text{and, therefore, of velocity head } \frac{v^2}{2g}\right)$ in the steady flow of water, implies a "loss of head" in the technical sense (*i. e.*, implying a corresponding loss of energy). It is worth while inquiring, then, what constitutes a "loss of head" in hydraulics, in the sense which implies a loss of energy. That there may be a

loss of velocity without any "loss of head," is immediately apparent when we examine that fundamental formula of hydraulics, viz., Bernoulli's theorem, for the steady flow of water without friction in (motionless) rigid vessels and pipes, as demonstrated and illustrated in all text books on hydraulics (see also Eq. (1) and context in Section 26 of the article, "Hydro-mechanics," *Encyclopædia Brittanica.*) This theorem may be thus written:

$$\frac{v_m^2}{2g} + \frac{p_m}{\gamma} + z_m = \frac{v_n^2}{2g} + \frac{p_n}{\gamma} + z_n \qquad (B)$$

in which m and n are any two positions (fixed in space) in the same stream line, while v_m and v_n denote the velocities of the water passing these respective points; p_m and p_n the internal pressure at m and n, and z_m and z_n the respective heights of m and n from an arbitrary horizontal datum plane situated below both m and n. γ denotes the weight of a unit of volume of water, and g the acceleration of gravity. Naming the terms in Eq. (B), each one of which is in quality a height, or "head," we may say, therefore, that in steady flow without friction, *the sum of the velocity head, pressure head and potential head* at any position (m) in a stream line, is equal to the sum of the corresponding heads at any other position (n) of the same stream line.

If each term in Eq. (B) is multiplied by W, the weight of water flowing per unit-time, it becomes an equation of energy, announcing that without friction the energy present at m, viz., the sum of the three forms, *kinetic energy*, *pressure energy*, and potential energy, is equal to the corresponding sum at n. [Rankine, p. 100, *Steam Engine*, uses the term actual energy for kinetic, and potential energy for the sum of what are here called pressure and potential energy.] It is, therefore, quite evident that if m and n are at the same level, and the kinetic energy at n is greater than that at n by a certain amount, then the pressure energy at m exceeds the pressure energy at n by an equal amount. (See p. 467, of "Hydro-mechanics," *Ency. Britt., Figs. 33* and *34*, for experiments by Mr. Froude, illustrating this fact.)

If, however, friction cannot be avoided (either *external*, against the vessel walls, or *internal*, through eddying, cross-currents, etc.), or if a motor of proper construction be interposed between m and n, m being down-stream from n, we find that in steady flow the

sum of the three heads at m is always less than that at n, and the deficiency is properly called a "loss of head" (Rankine) or "height of resistance" (Weisbach), and the product of this loss of head by the weight of flow per unit-time gives the energy spent by the water in friction (uselessly) or upon the motor (usefully) per unit-time (*i. e.*, the power). In the case of friction, or internal disturbance, loss of head is peculiarly well-named (as the lost energy cannot be regained in any manner), and is found to be so nearly proportional to the square of the velocity and independent of the pressure, that it is usually expressed in the form

$$\zeta \frac{v^2}{2g},$$

where ζ is a coefficient, found by experiment, and is approximately constant for a given fitting, such as an elbow, bend, short section of pipe having a sudden enlargement, etc., and v is the velocity where the disturbance occurs (or just down stream from it, if there is a change of section). This velocity may be an unknown quantity in some problems, but can usually be expressed in terms of the velocity at the discharging end of pipe.

(The only objects of introducing the $2g$ are that then, $v^2 \div 2g$ being a height, ζ must be an abstract number, and hence the same for any system of units, while $1 \div 2g$ occurs as a factor in other terms, rendering algebraic reduction somewhat simpler. Perhaps this will be satisfactory to M. Cazin. See article by him in *Van Nostrand's Mag.*, for Sept., '86.)

Hence, we may write Bernoulli's theorem, with friction, as follows (m being the down-stream position):

$$\frac{v_m^2}{2g} + \frac{p_m}{\gamma} + z_m = \frac{v_n^2}{2g} + \frac{p_n}{\gamma} + z_n - \Sigma_n^m \zeta \frac{v^2}{2g} \qquad \text{(BF)}$$

(As is well known, for a long pipe

$$\zeta = 4f \frac{l}{d},$$

where f ranges from ·0050 to ·0100, or more, and l = length and d = diameter of pipe.)

Let us apply eq. (BF) to the case of flow into the air through a circular "orifice in thin plate" in the vertical side of a large tank. Let h = vertical height of still surface (exposed to air) above centre

of orifice. Call the (practically) still surface position n, and take position m in the contracted section of jet where the filaments are parallel and consequently under atmospheric pressure. Also, let the datum plane pass through m. Then we must substitute

$$v_n = 0, \frac{p_n}{\gamma} = \text{height of water barometer} = b, z_n = h;$$

$$\frac{p_m}{\gamma} = b, z_m = 0,$$

while from experiment v_m has been found to be

$$= \phi \sqrt{2gh}$$

(ϕ being the "coefficient of velocity" for this case), so that

$$v_m^2 = \phi^2 2gh.$$

It is required to find ζ for the loss of head

$$\zeta \frac{v_m^2}{2g},$$

due to friction around the edges of orifice and contiguous portions of vessel wall. Hence, we obtain

$$\phi^2 h + b + 0 = 0 + b + h - \zeta \phi^2 h \qquad (1)$$

whence

$$\zeta = \frac{1}{\phi^2} - 1 \qquad (2)$$

Again, *Fig. 1*, let us consider a horizontal short pipe in the vertical side of the large tank, the case treated by Mr. Frizell (p. 287, JOURNAL OF THE FRANKLIN INSTITUTE, Oct., '86).

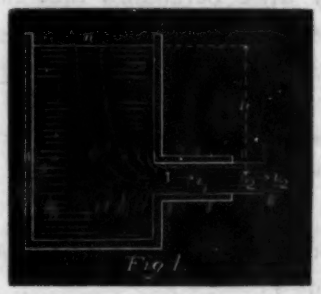


Fig 1

As before, take n in water surface, and m in the jet at outlet of pipe, where the filaments are parallel and pressure atmospheric; for m, however, let us write 2 to assume Mr. Frizell's notation. Call the contracted section 1 and denote by C the ratio which its

sectional area F_1 bears to that of the pipe F_2; *i. e.*, $F_1 = C F_2$, C being a "coefficient of contraction." Hence, $v_1 = v_2 \div C$. The loss of head between n and 1 is

$$\zeta \frac{v_1^2}{2g},$$

(where ζ has probably the same value as just found in eq. (2), though in the present case the pressure at 1 is much less than atmospheric,) and that lost between 1 and 2 (the *only* loss, begging Mr. Frizell's pardon, if we neglect the slight skin friction in pipe) is

$$\frac{(v_1 - v_2)^2}{2g}$$

by Borda's formula, for a sudden enlargement, *i. e.*,

$$\left(\frac{1}{C} - 1\right)^2 \frac{v_2^2}{2g}.$$

With these two losses of head, then, equation (BF) gives

$$\frac{v_2^2}{2g} + b + 0 = 0 + b + h - \zeta \frac{1}{C^2} \frac{v_2^2}{2g} - \left(\frac{1}{C} - 1\right)^2 \frac{v_2^2}{2g} \quad (3)$$

From (3), after substituting for ζ from eq. (2), we have

$$v_2 = \frac{1}{\sqrt{1 + \frac{1}{(\phi C)^2} - \frac{1}{C^2} + \left(\frac{1}{C} - 1\right)^2}} \sqrt{2gh} \quad (4)$$

If now we assume that C is equal to the coefficient of contraction for discharge through the circular orifice in thin plate into the air, then $\phi C = \mu =$ the coefficient of efflux for that orifice and eq. (4) reduces to Mr. Frizell's result. If with Prof. Unwin (*Encyc. Britann.*) we disregard the loss of head between n and 1, (4) reduces to

$$v_2 = \frac{1}{\sqrt{1 + \left(\frac{1}{C} - 1\right)^2}} \sqrt{2gh} \quad (5)$$

which is Prof. Unwin's form.

(Mr. Frizell has not quoted Prof. Unwin with strict accuracy, having replaced the latter's coefficient of contraction by μ, the coefficient of efflux for the thin-plate orifice.)

Since the only difference between Prof. Unwin's and Mr.

Frizell's treatment of this case (as far as the final result is concerned) consists in the consideration, by the latter, of the entrance friction, which the former does not introduce into his analysis, though he refers to it in the context; and since this friction is not a matter "of impact and momentum," like the resistance due to sudden enlargement further on, it is difficult to see that Mr. Frizell has presented the matter in any new light, except in advancing the novel idea that loss of head (or loss of energy as he calls it) depends only on loss of velocity, but that this idea is erroneous is made evident not only by examining Bernoulli's theorem, as already noted, but also in a striking manner by working a simple numerical example as follows: Let $h = 16$ feet in *Fig. 1*, then we compute v_2 to be $\cdot 815\sqrt{2gh} = 26\cdot 16$ feet per second. Taking 2 as datum plane, we see that the total head at n is composed of a velocity head of zero, a pressure-head of 34 feet, and a potential head of 16 feet; while at 2 we have a velocity-head of $(26\cdot 16)^2 \div 2g = 10\cdot 62$ feet, a pressure head of 34 feet, and a potential head of zero. The total loss of head then is $(0 + 34 + 16) - (10\cdot 62 + 34 + 0) = 5\cdot 38$ feet. In other words, each pound of water flowing has lost 5·38 foot-pounds of energy between n and 2, and no more, and this loss is mainly due to the sudden enlargement between 1 and 2.

But Mr. Frizell asserts that between positions 1 and 2 alone a loss of head has occurred of an amount

$$= \frac{v_1^2}{2g} - \frac{v_2^2}{2g} = \frac{v_2^2}{2g}\left(\frac{1}{C^2} - 1\right),$$

which if C be taken equal to 0·64 reduces to 15·30 feet, *almost the entire* 16 *feet head* $(= h)$ *under which efflux takes place.*

Aside from the facts already referred to on p. 467 of "Hydromechanics," *Encyc. Britann.*, a simple experiment with a common flexible rubber tube will convince any one that the loss of velocity occurring between the narrow and full section of a *gradual* enlargement, when the difference of sectional areas is not extreme, does not imply a corresponding loss of head, the loss of kinetic energy being made up by an equal gain of pressure energy. Suppose the tube attached at one end to a faucet and a jet at about 45° with the horizontal to be issuing from the other extremity, the flow steady. It will now be observed that a very considerable reduction of sec-

tion may be effected at any part of the tube (not so near the jet as to affect the area of its section) by compressing it between the thumb and finger, without appreciably affecting the range of the jet. [See also p. 885, Coxe's *Weisbach*.]

Another instance in point is the "Whirlpool Chamber," invented by Prof. James Thomson, and forming a special feature in the centrifugal pumps manufactured by Williamson Brothers, Kendal, Eng.

This chamber surrounding the centrifugal pump, by furnishing a gradual enlargement of passage way, gives opportunity for the kinetic energy stored in the water, where it leaves the pump blades with considerable velocity, to be gradually transformed into pressure energy, instead of being wasted in internal friction (*i. e.*, eddying), as with other kinds of centrifugal pumps.

As practical examples of the utilization of water-power in each of the three forms just mentioned, it is hardly necessary, perhaps, to call to mind the following familiar and well-marked cases:

(1.) The *vertical water wheel*, using energy in the potential or gravity form; *i. e.*, in passing through the wheel the water experiences no notable change, either in pressure or velocity, but simply in vertical position.

(2.) The *water-pressure engine*, which receives the liquid under pressure and rejects it under a considerably smaller pressure (less than atmospheric if a "draft-tube" is employed), no considerable change in velocity or vertical positions having occurred; *i. e.*, the motor uses the power in the pressure form.

(3.) The turbine of free deviation (and the Pelton "Hurdy Gurdy"), where the water has the same pressure and same vertical position at exit as at entrance, while its absolute velocity has been greatly reduced; *i. e.*, energy has been utilized in the kinetic form.

Cornell University, April 4, 1887.

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REPORT ON THE CHEMICAL COMPOSITION OF NATURAL GAS.

Made by PROF. FRANCIS C. PHILLIPS, of the Western University, Allegheny, for the Geological Survey of Pennsylvania.

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(*Concluded from vol. cxxiv, page 256.*)

The following experiments were tried at the valve house of the Philadelphia Company, in the rear of the office building, on Penn Street, Pittsburgh, beginning on March 22, 1887. A Woulfe's bottle containing 200 c. c. purified water, and a second bottle containing cuprous chloride, were connected with a gas meter, and gas allowed to stream slowly through them until 190 cubic feet had passed. The gas thus used comes directly from the Murrysville field. The gas was passed very slowly, so that three days were occupied in the transmission of the volume above named.

The water was then tested for ammonia by Nessler's reagent. No trace could be detected, although, as is well known, this reagent is capable of detecting $\frac{1}{200,000,000}$ part of ammonia in water, with great certainty.

The cuprous chloride was tested for both olefines and carbon monoxide by the method I have detailed, but no trace could be detected of either.

The composition of methane gas by weight is—

Carbon,	74·97	per cent.
Hydrogen,	25·03	"
	100·00	"

Hence this well produces gas approximating in composition to pure methane, and in this respect differs from all those from which samples have been taken. It may be here stated that at the time the sample was collected there was every reason to believe that the gas came exclusively from this one well.

No. 7, Raccoon Creek District. The sample was taken May 2, 1887, from the high pressure main of the Bridgewater Natural Gas

Company, at Rochester, Pa. The pressure at the time was sixty-seven pounds.

The gas is produced wholly from one sand, which is about 1,200 feet below the surface, on Raccoon Creek, in Beaver County. The Bridgewater Company owns twenty-three wells, and supplies the towns of Beaver Falls, Rochester, New Brighton, Phillipsburg, Van Port, Bridgewater, New Sheffield and Shannopin.

The Youngstown Company owns twelve wells in the same region. The gas is almost odorless and the wells produce little or no salt water and no oil.

On causing the gas to bubble through lime water for twenty minutes the fluid remained perfectly clear. After forty minutes a rapid stream of gas caused the lime water to become faintly milky, as seen in a bright light. The proportion of carbon dioxide was far too small to allow of an accurate eudiometric determination. The oxygen reaction was faint but decided.

This gas, on being passed for one hour into a nitrate of silver solution, produced a faint but decided reaction, indicating a trace of sulphuretted hydrogen.

In the statement below, the result of the carbon dioxide test at the main is given.

Determination of—	(1)	(2)	*Mean.*
Nitrogen, ...	10·00	9·82	9·91 per cent.

RESULTS OF ANALYSIS OF RACCOON CREEK GAS.

Nitrogen, ...	9·91
Hydrogen, ...	0·
Carbon dioxide, ...	trace.
Carbon monoxide, ...	0·
Olefines, ...	0·
Ammonia, ...	0·
Oxygen, ...	trace.
Sulphuretted hydrogen, ...	trace.
Paraffins, ...	90·09
	100·00

In a combustion of Raccoon Creek gas, 325·48 cubic centimetres yielded—

H^2O — 0·5108 gm., corresponding to H, — 0·05688 gm. = 23·60 per cent.
CO^2 — 0·6755 gm., " to C, — 0·18422 gm. = 76·40 "
100·00 "

Hence the paraffins in this gas contain per litre—

0·62827 gm. carbon.
0·19398 gm. hydrogen.

In a second combustion, 398·08 cubic centimetres gas yielded—

H^2O — 0·6254 gm., corresponding to H, — 0·06964 gm. = 23·56 per cent.
CO^2 — 0·8286 gm., " to C, — 0·22598 gm. = 76·44 "

100·00 "

Hence the paraffins contain per litre—

0·63010 gm. carbon.
0·19418 gm. hydrogen.

The means of these two results are per litre paraffins—

0·62918 gm. carbon, = 76·42 per cent.
0·19408 gm. hydrogen, = 23·58 "

100·00 "

This is the only gas which contains traces of sulphuretted hydrogen among those I have examined.

No. 8, Baden. Six miles southeast from Rochester, on the Pittsburgh, Fort Wayne and Chicago Railroad, Beaver County. The samples were taken May 18, 1887, from the Bryan well No. 2, one of four wells belonging to the Baden Gas Company. This gas is produced wholly from one sand, which is 1,396 feet deep, or about 1,300 feet below the Ohio River. This well was drilled in May, 1886.

The Baden wells are on the same anticlinal axis as the Raccoon Creek wells. This same axis continues northward a few miles east of the Speechley wells, near Oil City.

The gas exhibits a decided carbon dioxide and also an oxygen reaction.

Determinations of—	(1)	(2)	*Mean.*	
Nitrogen, . . .	12·26	12·38	12·32	per cent.
Carbon dioxide, .	0·41	0·41	0·41	"

RESULTS OF ANALYSIS OF BADEN GAS.

Nitrogen,	12·32
Carbon dioxide,	0·41
Oxygen,	trace.
Hydrogen,	0·
Carbon monoxide,	0·
Olefines,	0·
Ammonia,	0·
Paraffins,	87·27
	100·00

317·17 cubic centimetres of Baden gas yield on combustion—

H^2O — 0·4892 gm.,	corresponding	to H, — 0·05447 gm.	= 23·48	per cent.
CO^2 — 0·6510 gm.,	"	to C, — 0·17754 gm.	= 76·52	"
			100·00	"

Hence the paraffins of Baden gas contain per litre—

0·64142 gm. carbon.
0·19681 gm. hydrogen.

In a second combustion, 332·70 cubic centimetres yield—

H^2O — 0·5130 gm.,	corresponding	to H, — 0·057127 gm.	= 23·56	per cent.
CO^2 — 0·6843 gm.,	"	to C, — 0·18663 gm.	= 76·44	"
			100·00	"

Hence the paraffins contain per litre—

0·64276 gm. carbon.
0·19674 gm. hydrogen.

The means of these two results are per litre of paraffins—

0·64209 gm. carbon,	= 76·48	per cent.
0·19677 gm. hydrogen.	= 23·52	"
	100·00	"

No. 9, Houston well, Houston Station, two miles south of Canonsburg, on the Pittsburgh, Cincinnati and St. Louis Railroad, Washington County.

This well is situated one-third mile west of the Station, on Plum Run. It is drilled nearly through the Gantz sand, and is 1,794 feet deep. An upper gas-producing sand is found at 850 feet, but this is cased off, so that the well may be considered to yield gas from the Gantz sand exclusively.

The gas from the upper sand is said by well superintendents to burn with a whiter but more sooty flame than that from the greater depth. According to the statements generally heard at the wells, the occurrence of an upper, less productive gas-sand yielding gas of greater illuminating power, is a very common feature in many gas wells. The sample was collected on March 18, 1887.

The gas exhibits an oxygen reaction and causes a rapid precipitation in lime water.

Determinations of—	(1)	(2)	*Mean.*	
Nitrogen, ...	15·23	15·37	15·30	per cent.
Carbon dioxide, .	0·42	0·46	0·44	"

RESULTS OF ANALYSIS OF HOUSTON GAS.

Nitrogen,	15·30
Carbon dioxide	0·44
Oxygen,	trace.
Olefines,	0·
Carbon monoxide,	0·
Ammonia,	trace.
Hydrogen,	0·
Paraffins,	84·26
	100·00

310·20 cubic centimetres of Houston gas yielded on combustion—

H^2O — 0·4601 gm., corresponding to H, — 0·05124 gm. = 23·20 per cent.
CO^2 — 0·6217 gm., " to C, — 0·16955 gm. = 76·80 "
100·00 "

Hence the paraffins contain per litre—

0·64871 gm. carbon.
0·19602 gm. hydrogen.

In a second combustion, 293·35 cubic centimetres yielded—

H^2O — 0·4392 gm., corresponding to H, — 0·04891 gm. = 23·44 per cent.
CO^2 — 0·5855 gm., " to C, — 0·15968 gm. = 76·56 "
100·00 "

Hence the paraffins contain per litre—

0·64604 gm. carbon.
0·19786 gm. hydrogen.

The means of these two analyses are per litre of paraffins—

0·64737 gm. carbon, = 76·68 per cent.
0·19694 gm. hydrogen, = 23·32 "
100·00 "

The analyses above detailed were carried out with great care, and every known precaution observed in order to secure accuracy. The results represent the character of the gas from particular wells or group of wells, scattered over a large region, and as it flowed from the wells on a single day.

It is questionable whether they can be considered to represent the average composition of natural gas, for the reason that the gas territory is so vast in extent. According to the above results natural gas is not so complex a substance as has been heretofore supposed.

The samples examined may be said to consist simply of the hydrocarbons of the paraffin series, among which methane predominates. It is to these bodies that the fuel value of the gas is due. Inasmuch as most of the gas conveyed through pipe lines deposits little or no liquid hydrocarbons, it is evident that the higher paraffins are not present in notable quantity.

The method I have used in testing for the hydrocarbons of the olefine series enables me to state with much confidence that these bodies—ethylene, propylene, butylene, etc.—are absent. Hydrogen I have found in Speechley gas alone, although the utmost care has been taken in the examination.

Perhaps still smaller quantities may have escaped detection in other gas samples.

Sulphuretted hydrogen was found only in Raccoon Creek gas, but in faint traces. Oxygen is present in all, but in such small quantities that I have never succeeded in accurately determining its real percentage.

As nearly as I can estimate, the Wilcox contains more oxygen than any other, and Murrysville the least. Ammonia was found, in traces only, in Houston gas. Carbon monoxide was not found in any of the samples.

A comparison of the results in the accompanying table shows that the different gas samples differ mainly in the following particulars:

(1.) The proportion of carbon to hydrogen in the contained paraffins; that is to say, the ratio of the lower to the higher paraffins. Fredonia is seen to be the richest gas in carbon.

(2.) The proportion of nitrogen, which varies between 2·02 and 15·30 per cent. The three gas fields, Speechley, Baden and Raccoon Creek, approximately on the same anticlinal (according to Mr. I. C. White), produce gas having very different quantities of nitrogen.

The resemblance between the Fredonia, Sheffield, Kane, Wilcox and Raccoon Creek gas, as regards the proportion of nitrogen, is a matter of interest, although not explainable.

In the case of Murrysville, Speechley and Fredonia gas, the density, richness in carbon and calorific power of the contained paraffins are inversely as the proportion of nitrogen. It is a curious fact that there is a certain continuity as regards composi-

tion in the case of the Fredonia, Kane, Sheffield and Wilcox gases, which disappears on reaching the Speechley field. In proceeding southward south of Speechley, much greater differences occur.

TABLE I.

Constituents.	Fredonia.	Sheffield.	Kane.	Wilcox.	Speechley.	Lyon's Run near Murrysville.	Raccoon Creek.	Baden.	Houston.
Nitrogen,	9'54	9'06	9'79	9'41	4'51	8'08	9'91	12'32	15'30
Carbon dioxide,	0'41	0'30	0'20	0'21	0'05	0'48	trace.	0'41	0'44
Hydrogen,	0'	0'	0'	0'	0'02	0'	0'	0'	0'
Ammonia,	—	0'	0'	0'	0'	0'	0'	0'	trace.
Oxygen,	trace.	trace.	trace.	trace.	trace.	trace.	trace.	trace.	trace.
Sulphuretted hydrogen,	—	0'	0'	0'	0'	0'	trace.	0'	0'
Paraffins,	90'05	90'64	90'01	90'38	95'42	97'70	90'09	87'27	84'26
	100'00	100'00	100'00	100'00	100'00	100'00	100'00	100'00	100'00
The paraffins contained in these gas samples have the following composition *by weight:*									
Carbon,	78'14	76'69	76'77	76'52	77'11	74'96	76'42	76'48	76'68
Hydrogen,	21'86	23'31	23'23	23'48	22'89	25'04	23'58	23'52	23'32
	100'00	100'00	100'00	100'00	100'00	100'00	100'00	100'00	100'00

(3.) The carbon dioxide, which varies within very narrow limits The only gas in which it disappears is that from Raccoon Creek, although Speechley gas contains barely more than at race.

At Oil City, a sand is found 582 feet below low water mark in the Allegheny River, which produces gas of low pressure, amounting, it is said, to twenty pounds when shut in for some time. This gas is used in the Oil Well Supply Company's works for heating purposes.

It bears the same relation to the Speechley gas-sand, 1,900 feet deep, as the shallow gas sands usually to the deeper and more productive sand rocks.

A determination of the nitrogen in the gas from this upper rock gave 5·62 per cent. Speechley gas contains 4·51 per cent. The sample was collected on April 13th, the day on which the Speechley samples were taken.

The Speechley gas wells are six miles distant from this well. Tests for hydrogen, olefines, carbon monoxide, and dioxide and ammonia in this gas all led to negative results.*

In conclusion, I have to express my indebtedness for information and for facilities in conducting tests and examinations at the wells, to the following gentlemen: Mr. K. Chickering, of the Oil Well Supply Company, Oil City; Mr. W. C. Henry, of the United Natural Gas Company, Wilcox; Mr. Walter Horton and Mr. John McNair, of Sheffield; Mr. J. D. Bruder, of Kane; Mr. E. J. Crissey, of Fredonia; Mr. S. F. Gayley, of Rochester; and to the officers of the Philadelphia Gas Company, the Baden Gas Company, and the Pennsylvania Gas Company, of Pittsburgh.

* For the information of those who are not familiar with the chemistry of the subject, it may be of importance to call attention to the two very different modes of occurrence of hydrogen in fuel gases.

As *free* or *uncombined* hydrogen, it is often reported to occur in considerable quantity in natural gas, and constitutes often from thirty to forty per cent. of ordinary coal gas.

In this form of *free* hydrogen, it may be separated and removed more or less completely from the other gaseous constituents by exposure of the gas to a porous wall of plaster, through which the extremely light, *free* hydrogen more readily passes. In the above detailed analyses, *free* hydrogen was found in a single instance, and in traces only (Speechley gas).

In chemical union with carbon, hydrogen constitutes about one-fourth part by weight of all the natural gas now used as fuel in Pennsylvania. In this form of occurrence, as a hydrocarbon, hydrogen cannot be separated from the other constituents by mechanical means. The products of the combustion of all such gas will be the same in kind—carbon dioxide and water—whether the hydrogen be present wholly as a hydrocarbon, or partly as such and partly *free*.

CALCULATION OF THE FUEL VALUE OF NATURAL GAS.

The calorific power of any combustible may be determined by measuring the number of kilogrammes of water heated from 0° to 1° by one kilogramme of the fuel in burning, or by a calculation. The difficulties and inconveniences encountered in the first method necessitate commonly a resort to the second.

Pure charcoal, in burning, produces, according to the researches of Favre and Silbermann (in 1849), 8,080 heat units, or one kilo. in burning will raise the temperature of 8,080 kilos. of water from 0° to 1° C.

By the same authors it was found that one kilo. of hydrogen in burning, generates a quantity of heat sufficient to warm 34,462 kilos. of water from 0° to 1° C.; that is, 34,462 heat units. Later determinations have been made by various authors, the most important being by Thomsen, who found 34,180 (*Berichte der deutschen chemischen Gesellschaft*, 1873, p. 1883), and by Berthelot, who obtained the number 34,600 (*Comptes Rendus*, 1880, p. 1240). The value assigned by Thomsen, viz., 34,180, is probably the more correct.

If it were possible that a fuel should contain pure hydrogen and charcoal, a calculation of its heating power would lead to very correct results. It is found, however, that when a *compound* of carbon and hydrogen is burned, the number of heat units produced will not equal the number obtained when the same quantities of carbon and hydrogen are burned separately.

Thus a kilo. of methane produces 13,270·5 heat units, but if the same quantities of carbon (as charcoal) and hydrogen were burned separately in a calorimeter, 14,613 heat units would result (assuming that the carbon produces 8,080 and the hydrogen 34,180 heat units per kilo. burned).

This difference between the calculated amount of heat, and the actually available heat, 14,613 — 13,270 = 1,343 heat units is 9·19 per cent. of the theoretical yield. For practical applications, this is a loss of heat, which must be considered to represent the quantity of energy required to overcome the mutual affinity of the carbon and hydrogen, which are to be first separated before they are burned to carbon dioxide and water.

With more complex compounds the available heat of combustion does not fall so far short of the theoretical maximum, and it may

be stated in a general way that the greater the number of carbon atoms in the compound the more closely will the available and actual number of heat units coincide. This statement is especially true of certain series of hydrocarbons. The following table will serve to illustrate this in the case of the first three members of the paraffin series. For the higher paraffins no determinations have yet been made:

TABLE II.

SHOWING RATIO OF AVAILABLE TO CALCULATED HEAT OF COMBUSTION IN THE CASE OF CERTAIN HYDROCARBONS.

Name.	Symbol.	Calculated Heat Units, assuming that the Carbon and Hydrogen produce the Maximum of Heat and are burned separately.	Available Heat as determined by Calorimetric Measurement.	Percentage of Available on Theoretical Maximum of Heat Units.
		Per Kilo. of Paraffin.	Per Kilo. of Paraffin.	
Methane,	CH^4	14,613	13,270	90·81
Ethane,	C^2H^6	13,310	12,373	92·95
Propane,	C^3H^8	12,835	12,052	93·89

It has been shown by Thomsen that isomeric hydrocarbons, or those which differ in properties, though having identical composition, may produce different quantities of heat when burned. Thus—

	Symbol.	*Heat Units.*
Propylene,	C^3H^6	11,757
Trimethylene,	C^3H^6	10,917
Difference,		840

The chemical formulæ given show them to have the same composition, and yet these hydrocarbons would be represented by different values, if used as fuels.

The presence of isomers among the hydrocarbons of natural gas would tend to interfere with the correctness of a calculation of its fuel value.

No isomers are known in the case of methane (CH^4).

Berthelot has stated that a second hydrocarbon isomeric with ethane (C^2H^6) exists, which produces on burning 12,776 heat units, instead of 12,373, the number as determined by Thomsen.

Thomsen's researches have disproved this assertion, however, and have shown conclusively that ethane produced in a variety of ways invariably possesses the same calorific power (*Berichte der deutschen chemischen Gesellschaft*, 1881, p. 500). Isomers of the higher paraffins no doubt occur in gas as well as in petroleum, but when it is considered that in gas the higher paraffins occur only in small quantity, and moreover that the calculated and the available calorific power differ much less in these higher members than in methane and ethane, the danger of error from the presence of such isomers cannot be considered likely to effect the calculated results.

The calorific power of methane was determined by Andrews in 1848, as 13,108 heat units (*Philosophical Magazine*, 1848, p. 321), and by Favre and Silbermann in 1853 as 13,063 heat units.

In 1880, Thomsen assigned it the value 13,345·6, and this number agrees closely with that obtained by Berthelot in the same year, viz., 13,343·8. More recently Thomsen has corrected his former result, and now gives 13,270·5 as the most probable number (Berthelot, *Comptes Rendus*, 1880, p. 1240). Thomsen (*Berichte der deutschen chemischen Gesellschaft*, 1880, p. 959 and 1321, ref., and 1887, p. 77, ref.).

The elaborate researches of Julius Thomsen in thermo-chemistry (*Thermo-chemische Untersuchungen*, Leipzig) have reached the fourth of a series of large volumes, and although designed primarily as a contribution to theoretical chemistry, they supply data likely to prove of great value in the study of fuels for metallurgical and other technical purposes.

The actual calorific power of a gas fuel may now, by the use of such data, be more satisfactorily determined by calculation, provided its composition is known, than by the use of a calorimeter. In this respect, there is an important difference between gas fuels and the various kinds of coal. Coal being a compound of carbon, hydrogen and oxygen, of a highly complex character, or possibly a mixture of such compounds, no such plainly definable relationship exists between the theoretical maximum and the available heat quantity per unit-weight burnt.

The percentage composition by weight of the paraffins likely to occur in natural gas is expressed in the following table. Small quantities of condensable vapor of higher paraffins occur in the gas

in some places, as is evident by the condensation of benzine in pipes. The heavier vapors occur usually in very minute quantity, if at all.

TABLE III.

SHOWING THE COMPOSITION BY WEIGHT OF SOME OF THE LOWER PARAFFINS.

Name.	Symbol.	Per Cent. Carbon.	Per Cent. Hydrogen.
Methane,	CH^4	74·97	25·03
Ethane,	C^2H^6	79·96	20·04
Propane,	C^3H^8	81·78	18·22
Butane,	C^4H^{10}	82·72	17·28
Pentane,	C^5H^{12}	83·29	16·71

The analyses of natural gas above detailed show a variation in the proportion of carbon and hydrogen in the case of the two extremes of 3·18 per cent. Thus, the paraffins of Murrysville gas contain—

Carbon,	74·96	per cent. by weight.
Hydrogen,	25·04	" "
	100·00	" "

and in case of Fredonia gas—

Carbon,	78·14	per cent. by weight.
Hydrogen,	21·86	" "
	100·00	" "

From the tabular statement of the composition of the lower paraffins, it appears that Murrysville gas, as obtained at the Hukill well, has nearly the composition of methane, while, disregarding again the nitrogen and carbon dioxide present, the Fredonia gas, the richest in carbon, approximates in composition to a mixture of equal volumes of methane and ethane, of which the actual composition would be by weight—

Carbon,	78·22	per cent.
Hydrogen,	21·70	"
	100·00	"

By this I do not imply that it actually contains these two paraffins in the proportions named, for it is possible that the gas in question contains more of methane and a very small quantity of some of the higher paraffins, propane, or quartane, etc.

As I have stated in regard to the analyses, the exact determination of the percentage of individual paraffins is a matter of such extreme difficulty that it may be considered practically impossible.

If we assume that Fredonia gas really contains equal volumes of methane and ethane, and calculate its calorific power accordingly, the following error may be committed. The gas may contain a larger amount of methane than was assumed, and consequently a very small quantity of quartane or pentane, *for although the percentage of carbon and hydrogen is definitely fixed by the analysis, it is still a question as to the arrangement of the carbon and hydrogen in the form of higher or lower paraffins.* As the difference between the available and theoretical heat of combustion is greater in the case of methane and less in the higher paraffins, an under-estimate of the quantity of methane would lead to too high a value for the available heat of combustion. On the other hand, an under-estimate of the proportion of the higher paraffins would cause the available heat, as expressed in heat units, to be rated too low, supposing that in both cases the absolute quantities of carbon and hydrogen remained constantly the same.

This error would be small in most instances, but in the extreme case of the two gases, consisting of methane and ethane, respectively, the error from this source would exceed one per centum. I have attempted to correct this error, as will be shown below.

The curious and intimate relationship of the paraffins is well illustrated by the fact that a mixture of one cubic metre each of methane, ethane and propane will contain the same proportions of carbon and hydrogen, and will consequently yield the same quantities on burning of CO^2 and H^2O as three cubic metres of the intermediate hydrocarbon ethane.

1 cubic metre of methane weighs 0·7148 kilos., and generates heat units, ...	9,485
1 cubic metre of ethane weighs 1·34016 kilos., and generates heat units, ...	16,582
1 cubic metre of propane weighs 1·9656 kilos., and generates heat units, ...	23,688
Total, ...	49,755
3 cubic metres of ethane generate on burning heat units, .	49,746
Difference, ...	9

The numbers expressing the heat produced are obtained by

multiplying the weight of the cubic metre by 13,270, 12,373 and 12,052, respectively, as given in Table II.

The difference is so slight, amounting to only nine heat units, that it is evident that it would have been sufficiently accurate to assume this mixture of three hydrocarbons to consist of the intermediate member, ethane, in so far as the calculation of the fuel value is concerned.

Or it may be more broadly stated that, with a view to the calculation of the calorific power of natural gas, it is sufficiently accurate to assume that the natural gas (containing no hydrocarbon of the olefine series) has the simplest constitution consistent with its percentage by weight of carbon and hydrogen, and then to determine its fuel value accordingly.

Fredonia gas, as shown in the table of analyses, consists of 90·05 per cent. of paraffins, together with 9·54 per cent. of nitrogen and 0·41 per cent. carbon dioxide. The paraffins in this gas consist of 0·80406 kilo. carbon and 0·22494 kilo. hydrogen per cubic metre.

The theoretical maximum of heat units for these paraffins is calculated as follows:

$$\begin{aligned} 0{\cdot}80406 \times 8{,}080 &= 6{,}497 \\ 0{\cdot}22494 \times 34{,}180 &= 7{,}288 \\ \hline & 13{,}785 \end{aligned}$$

When CH^4 burns, only 90·81 per cent. of the theoretical heat is available. When C^2H^6 burns, 92·95 per cent. can be utilized.

Hence if Fredonia gas is to be looked upon as a mixture of equal volumes of the two hydrocarbons methane and ethane, it will contain about one and 1·87 parts by weight, respectively, or approximately two parts by weight of ethane and one of methane.

The available heat of combustion can be determined by multiplying the theoretical maximum by a factor which is intermediate between ·9081 and ·9295, and as a very close approximation the fraction

$$\frac{2\ Et. + Mt.}{3 \times 100}$$

will, I think, be sufficiently accurate. In this, *Et.* equals the percentage of available on theoretical maximum heat for ethane, and

Mt. equals the same ratio for methane. Substituting in this fraction

$$\frac{2 \times 0{\cdot}9295 + 0{\cdot}9081}{3} = {\cdot}9224.$$

The theoretical maximum heat of combustion of the Fredonia gas as calculated above, is 13,785 heat units.

Then, $13{,}785 \times 0{\cdot}9224 = 12{,}715$ as the available heat units due to the paraffins in the gas. As there are 90·05 of paraffins, the remainder consisting of nitrogen and carbon dioxide, the above number will be still further reduced and $12{,}715 \times 0{\cdot}9005 = 11{,}450$, the available heat produced by one cubic metre of Fredonia gas.

In the case of the gas from Sheffield, Kane, Wilcox, Raccoon Creek, Baden and Houston, there is a general similarity as regards the percentage of carbon and hydrogen. Wilcox gas may be regarded as representing approximately the average, and as a calculation shows that a mixture of four volumes of methane and one volume ethane contains carbon 76·54 and hydrogen 23·46, we may, for the purpose of the present calculation assume that the above-mentioned six gases contain approximately these proportions of the two named paraffins. For such a mixture, the factor by which to obtain the available calorific value, will be

$$\frac{2\,Mt. + Et.}{3 \times 100} = 0{\cdot}9152.$$

This factor has accordingly been used in the case of the above-named gases. Speechley gas may be considered to contain five volumes of methane and two volumes of ethane, for the purpose of the present calculation, and the factor will be

$$\frac{3\,Et. + 4\,Mt.}{7 \times 100} = 0{\cdot}9173.$$

Murrysville gas contains nearly pure methane, and consequently the factor will be ·9081.

It is not implied in the above consideration that the actual proportions of what may be regarded as the most commonly occurring paraffins—CH^4, C^2H^6, C^3H^8, etc., can be accurately stated, for this I believe to be impossible. These proportions have been assumed as not inconsistent with the analytical data, merely for the purpose of obtaining approximately correct values for the factors to be used in the calculation of the calorific power of gas.

The following table, IV, contains the results of the calculation carried out as explained. Column No. 2 in this table expresses the quantities of carbon and hydrogen contained in one cubic metre of each gas. In Column No. 3 are given the factors, the derivation and use of which has already been pointed out.

TABLE IV.

FUEL VALUE OF NATURAL GAS.

Gas Fields.	2		3	4	5	6	7
	Weight in Kilos. of Carbon per Cubic Metre of Paraffins.	Weight in Kilos. of Hydrogen per Cubic Metre of Paraffins.	Factor.	Available Heat Units per Cubic Metre of Gas.	Available Heat Units per 100 feet of Gas.	Pounds of Water at Boiling Point, evaporated by 100 feet of Gas.	Pounds of Pure Charcoal, equal in Heating Effect to 100 feet of Gas.
Fredonia,	0·80406	0·22492	0·9224	11,449	32,421	133·30	8·845
Sheffield,	0·65526	0·19024	0·9152	10,040	28,430	116·89	7·756
Kane,	0·65669	0·19866	0·9152	10,354	29,319	120·54	7·999
Wilcox,	0·64622	0·19828	0·9152	9,925	28,102	115·54	7·667
Speechley,	0·69837	0·20738	0·9173	11,144	31,554	129·73	8·609
Lyon's Run, near Murrysville,	0·53741	0·17950	0·9021	9,296	26,321	108·22	7·181
Raccoon Creek,	0·62918	0·19408	0·9·32	9,661	27,355	112·47	7·463
Baden,	0·64209	0·19677	0·9152	9,515	26,941	110·77	7·350
Houston,	0·64737	0·19694	0·9152	9,224	26,119	107·38	7·126

1 cubic metre = 35·3166 cubic feet.

1 kilogramme = 2·20462 pounds avoirdupois.

This factor is a fraction. Its numerator represents the actual number of heat units produced in the burning of the unit-weight of the total paraffins, the number being ascertained from a consideration of the percentage of carbon and hydrogen in the gas. The denominator represents the number of heat units obtained when the quantities of contained carbon and hydrogen are multiplied by the numbers 8,080 and 34,180 respectively, and the products added.

Column No. 4 gives the actual fuel value of each gas expressed in heat units per cubic metre. These numbers represent the heat of combustion calculated for the carbon and hydrogen separately, these two added together, and their sum multiplied by the corresponding factor in No. 3.

The numbers in Column No. 5 indicate kilogrammes of water which can be warmed from 0° to 1° C. when 100 cubic feet of the

respective gas, measured at 0° C., and under a barometric pressure of seventy-six centimetres, are burned at an initial temperature of 18° C., or 64°·4 F. (This last is the temperature assumed by Thomsen in his determinations), and assuming that the products of combustion are liquid water and gaseous carbon dioxide.

In Column No. 6 are stated the numbers of pounds avoirdupois of water which, theoretically, should be boiled away at 100° C. into steam at the same temperature, and under atmospheric pressure, when 100 cubic feet of gas are burned. The latent heat of evaporation of water in this calculation has been assumed as 536·2 heat units (Berthelot, *Comptes Rendus*, 1877, p. 646).

In the seventh column a comparison is given between gas and pure charcoal, assumed free from ash. Charcoal has been chosen rather than coke or coal, for the reason that exact calorimetric data as to the latter fuels are as yet difficult to obtain, and calculated values are uncertain.

An impression prevails, based partly upon analytical data, and partly upon a supposed variation in the steam-producing power, that natural gas is subject to constant fluctuations in composition. To what extent such fluctuations are liable to affect the value of the results of the above calculations, I am wholly unable to state.

In view of these reported changes, it is to be regretted that more abundant data are not at hand upon which to base a conclusion as to the real nature of the fluctuations in composition. If such changes occur, are they progressive or irregular? Are they of such a character as to cast any light upon the question of origin, which every one asks but no one can answer? Are they to be regarded as a factor in determining the durability of a gas well?

DOWNWARD-DRAUGHT FURNACES.

CARLOS A. LOZANO and H. F. T. ERBEN.*

The idea of drawing or forcing the air downward through the burning coal, instead of upward, is not new; but Messrs. Post and Sawyer have made a device, with a grate kept at comparatively low temperature, by the circulation of water in the pipes used as grate bars, which has been the means of making the downward-draught furnace a practicable reality. They designed attachments for application to various kinds of boilers in place of the ordinary furnace, a number of which are said to be in successful operation, and the present device was claimed to be superior to any other boiler furnace, and capable of improving the performance of any boiler whatever.

Having undertaken, for our graduating thesis, an investigation of this new furnace, with a view to find out what advantages, if any, were to be gained by it, specially if any improvement in the combustion or any diminution in the quantity of the air of dilution, we arranged with the agents of the device, and with the engineers, Messrs. Richard H. Buel and E. E. Magovern, who had been engaged to make certain tests, to assist in the tests and take all the data we wanted during them.

The experiments were made upon a return tubular boiler, first with the boiler and ordinary furnace as it originally stood, and then after the Post and Sawyer device had been attached; the firing being conducted by the same man, Mr. J. F. Ayer, an expert fireman, in the employ of Messrs. Post and Sawyer, and the coal used being of one kind, an amount sufficient for the two tests having been stored for the purpose.

Both tests were conducted at the maximum rate of combustion possible under the existing natural draught.

The following is an account of the observations taken, and a few deductions therefrom.

BOILER PLANT.

The boiler plant consisted of a cylindrical tubular boiler, 14 feet long, 5 feet diameter, having 90 tubes, 3 inches external dia-

* Graduation Thesis.—Stevens Institute of Technology.

meter, and a steam drum, diameter 30 inches, height 24 inches, near the top of which drum, or dome, the steam pipes are connected at the front and back; plain brick setting, internal distance between side walls, 5 feet; grate horizontal, 5 x 5 feet, and 22 inches below the shell of the boiler; bridge wall horizontal, 6½ inches below the shell; one-half of the shell exposed to the products of combustion, these passing back under the boiler, and then returning through the tubes into front connection, to be carried off by an iron flue, 20 inches in diameter, this latter discharging into a rectangular iron stack, 3 feet 11 x 7 inches in cross section and 110 feet high. The bottom of the glass gauge was on a level with the top of the upper row of tubes. The upper part of the shell and the steam drum were covered with asbestos. The feed water was admitted into the boiler at the bottom, near the back end, after having passed through a feed-water heater heated with exhaust steam.

DOWNWARD-DRAUGHT ATTACHMENT.

Attached to the border above described was the Post and Sawyer's downward-draught device, as intended for application to externally fired tubular boilers.

The attachment referred to consisted of steel water-leg, 4 feet 6 inches wide, 12 inches deep at top, and 8¾ inches deep at bottom, extending 3 feet below the shell of the boiler; 2 inclined circulating pipes, not in the picture, 4 inches diameter, 56¾ inches long, connecting the sides of the water-leg near the bottom with the sides of the boiler shell near the front; one vertical circulating pipe, 4 inches diameter, 44½ inches long; 21 pipes forming grate-bars, 1½ inches diameter, 54⅜ inches long, set highest at the back, at an inclination of 2 inches to the foot; seven circulating pipes, 3 inches diameter, 55⅝ inches long, highest at the front and having a drop of ¾ inch per foot; seven headers connecting the pipes of the water-grate in groups of 3 with the 3-inch circulating pipes; a branch of the feed pipe, connecting with the water-leg near the bottom, opposite the vertical circulating pipe, so that the feed water divided, part going directly into the boiler at the bottom near the back, as before, and part entering the water-leg first.

DIMENSIONS COMPARED.

Item.		Before Change.	With the Post and Sawyer Attachment.
Grate surface, square feet,		25·	20·
Air space over bridge wall, square feet,		2·89	4·27
Air space in grate bars, square feet,		6·6	4·89
Internal area of boiler tubes, square feet,		3·8	3·8
Area of round flue, square feet,		2·18	2·18
Area of rectangular flue, square feet,		2·29	2·29
Water heating surface, square feet.	Boiler proper,	1127·13	1122·34
	Attachment,	. . .	127·29
	Total,	1127·13	1249·63
Ratios to grate surface,	Water heating surface,	45·09	62·72
	Air space in grate bars,	·264	·225
	Air space over bridge wall,	·116	·214
	Internal area of tubes,	·152	·190
	Area of round flue,	·087	·109
	Area of rectangular flue,	·091	·115

RECORD OF THE OBSERVATIONS DURING THE FIRST TEST.

May 5–6. 94 Liberty Street, N. Y.

Time.	Steam Gauge pressure lbs per sq. in.	Draft Inches of Water.	Height of Water in glass gauge. Inches.	Coal. Pounds.	Feed. Pounds.	Water Meter Readings. Cubic Feet. (Uncorrected Readings)	Barometer Inches.	Thermometer Attached to the Barometer. F.
10 A. M.	62	·2	3·75	840	2,660	7511·	30·21	89·
11	59	·3	3·625	420	2,660	7542·5	30·22	89·
12 M.	40	·15	2·75	140	1,900	7585·	30·20	88·2
1 P. M.	44	·1	3·75	700	2,280	7628·	30·20	87·
2	41	·1	1·5	. .	1,900	7658·5	30·17	97·
3	41	·1	1·6	420	2,660	7700·5	30·18	86·5
4	39	·1	3·	. .	3,040	7743·	30·16	86·
5	42	·1	1·	420	1,520	7774·	30·17	86·
6	43	·1	2·5	280	3,040	7820·	30·15	87·
7	60	·1	3·5	560	2,660	7864·3	30·18	89·
8	48	·1	2·75	. .	2,660	7906·	30·23	89·
9	65	·1	2·75	280	2,280	7946·	30·21	88·
10	63	·1	3·75	280	2,660	7990·	30·22	88·
11	52	·05	2·4	312	1,900	8018·	. .	. .
12 Mid.	65	·2	4·	. .	3,420	8064·	. .	. .
1 A. M.	. .	. .	. .	. .	380	8079·	. .	. .
	164 / 15	2·1 / 15	42·625 / 15			605½ × 62·3538	392·5 / 13	1149·7 / 13
	= 50·9	= ·14	= 2·84	4,652	37,620	= 37755 Pounds.	= 30·2 = 30·05 at 32° F.	= 88°·4

Time.	Temperature Fahrenheit.					
	Feed,		Fire Room.		Flue.	
	Initial.	Final.	Dry Bulb.	Wet Bulb.	Thermometer	Pyrometer. (Uncorrected Readings.)
10 A. M.	. . .	103	108·7	96 3	370	430
11	. . .	145	108·	96·2	350	410
12 M.	. . .	197	110·7	95 3	310	380
1 P. M.	. . .	197	112·5	96·	330	400
2	. . .	200	112·	95·5	. .	380
3	. . .	197	110·	96·	. . .	400
4	62 25	200	110·5	97·	. . .	375
5	68·	200	112·	96·	. . .	380
6	63·	200	112·	95·	. . .	400
7	61·	200	108·	97·	. . .	410
8	62·	190	112·	97·	357	410
9	. . .	180	112·	97·	338	408
10	. . .	210	112·	95·	338	410
11	60·	200	106·	95·	348	412
12 Mid.	. . .	200	112·	94·	. . .	400
	376·25 / 6	2819 / 15	1658·4 / 15	1438·3 / 15	2741 / 8	6005 / 15
	= 62·7	= 187·9	= 110·6	= 95 9	= 342·6 Probable mean all the time, 340°.	= 400·3

Remarks.

Hauled fire at 8.30 A. M.
Steam pressure, 65. Water gauge, 4 inches.
Started fresh fire at 8.42 A. M., with 323·5 pounds of wood, equivalent to $·4 \times 323·5 = 129·4$ pounds coal.
Steam pressure, 60. Water gauge, 4 inches.
Trial ended at 12.42 A. M.
Steam pressure, 60. Water gauge, 4 inches.
Commenced to feed at 8.47 A. M.
Put on first coal at 8.49 A. M.
Fired 23 times during the test.
Sliced the fire 8 times.
Cleaned the fire once.

Contents of the furnace and ash pit weighed at the end of the test,	1,261 pounds.
Picked out unburned coal,	713 "
Ashes,	548 "
Meter at commencement of the test,	7473·5
Meter at end of the test,	8079·
Cubic feet,	605·5

Made two tests of furnace temperature, heating 1·6824 kilogrammes of wrought iron in the furnace, and putting it into 100 pounds water, raising the temperature 10° in each case.

	Pounds.
Coal fed,	4,652
Wood equivalent,	129·4
	4,781·4
Picked from ashes,	713
Coal burned,	4,068·4
Moisture in the coal, 4781·4 × ·0385,	184·1
Dry coal burned,	3,884·3
Ashes,	548·
Combustible burned,	3,336·3

The following is Mr. E. E. Magovern's record of his calorimeter experiments:

Number of Test.	Weight of Water in Calorimeter. Pounds.		Temperature of Water. F. Degrees.		Steam Pressure Pounds per Square Inch.	Duration of Test. Minutes.
	Initial.	Final.	Initial.	Final.		
1	305·	339·	62·3	164·	39	5·033
2	304·	314·37	68·	101·	40	1·5
3	304·1	318·6	63·	110·	55	2·033
4	304·2	343·7	61·	178·	60	5·038
5	304·5	329·12	62·	146·	60	3·046
6	304·3	324·7	60·	131·	60	2·55

RECORD OF THE OBSERVATIONS DURING THE SECOND TEST.

June 21–22. 94 Liberty Street, N. Y.

Time.	Steam Gauge pressure lbs per sq. in.	Draft Inches of Water.	Height of Water in glass gauge. Inches.	Coal. Pounds.	Feed. Pounds.	Water Meter Readings. Cubic Foot.	Barometer Inches.	Thermometer attached to the Barometer. F.
9 A. M.	54	·1	3·75	1,120	3,040		30·07	94·
10	48	·1	4·	. . .	1,900		30·07	95·5
11	40	·1	3·875	420	1,900		30·07	95·5
12 M.	41	·1	3·	140	1,520		30·07	97·
1 P. M.	58	·25	4·	420	1,900		30·10	96·
2	59	·3	2·5	. . .	1,140		30·06	96·
3	42	·3	2·06	280	1,900		30·07	96·3
4	49	·25	2·5	280	1,900		30·	96·5
5	62	·3	1·5	280	1,520		29·96	96·
6	26	·4	3·125	. . .	2,660		29·97	96·
7	60	·4	3·25	280	1,520		29·97	96·
8	55	·5	2·875	280	1,900		29·95	97·5
9	55	·5	3·5	280	2,280		30·	96·
10	50	·45	4·5	. . .	1,900		30·	96·5
11	61	·4	4·	. . .	1,520		29·99	94·5
12 Mid.	. .	. . .	. . .	. . .	1,140		. . .	. . .
	760 / 15	4·45 / 15	48·435 / 15	3,780	29,640		450·35 / 15	1439·3 / 15
	= 50·7	= ·3	= 3·23				= 30·02	= 96
	Coal weighed back, —			88 / 3,692			= 29·839 at 32° F.	

Meter out of order.

Time.	TEMPERATURE FAHRENHEIT.					
	Feed.		Fire Room.		Flue.	
	Initial.	Final.	Dry Bulb.	Wet Bulb.	Thermometer.	Pyrometer. (Uncorr'ted Readings.)
9 A. M.	75	200	104·3	95·	322	400
10	76	210	107·2	100·	310	400
11	76	210	108	98·	282	380
12 M.	76	210	109	98·	276	370
1 P. M.	76	212	106·5	96·	293	385
2	77	195	105	96·5	. .	390
3	77	210	108	100·	. .	385
4	. .	. .	110	101·5	. .	375
5	76	190	109·5	99·	. .	380
6	76	210	108	98·	278	380
7	77	205	108	97·5	306	415
8	76	210	106·5	97·5	314	415
9	77	205	109	98·5	294	400
10	77	205	105	95·	290	390
11	78	125.	104·5	95·	288	390
	1070 / 14	2797 / 14	1608·5 / 15	1465·5 / 15	3253 / 11	5855 / 15
	= 76·4	= 199·1	= 107·2	= 97·7	= 295·7 Probable mean all the time, 293°.	= 390·3

Remarks.

Hauled fire at 7.37 A. M.
Steam pressure, 60. Water gauge, 4 inches.
Started fresh fire at 7.43 A. M., with 338 pounds of wood, equivalent to $\cdot 4 \times 338 = 135 \cdot 2$ pounds coal.
Steam pressure, 60. Water gauge, 3·5 inches.
Trial ended at 12 mid.
Steam pressure, 48. Water gauge, 4 inches.
Commenced to feed at 7.54 A. M.
Put on first coal at 7.56 A. M.
Fired 29 times during the test.
Sliced the fire 14 times.
Cleaned the fire 4 times.
Contents of the furnace and ash pit weighed at the end of the test, ... 994 pounds.
Picked out unburned coal, ... 417 "

Ashes, ... 577 "

Made two tests of furnace temperature, heating 1·2645 kilogrammes of wrought iron in the furnace, and putting it into 100 pounds water, raising the temperature—

In experiment 1, ... 11°·5 F.
In experiment 2, ... 12°· F.

	Pounds.
Coal fed, ...	3,692·
Wood equivalent, ...	135·2
	3,827·2
Picked from ashes, ...	417·
Coal burned, ...	3,410·2
Moisture in the coal, 3,827·2 × ·0355 = ...	136·
Dry coal burned, ...	3,274·2
Ashes, ...	577·
Combustible burned, ...	2,697·2

Through inadvertency, the level of the water in the boiler was ½ inch higher at the end of the test than it should have been. On the other hand, as steam was drawn from the boiler for use, the pressure became too low to end at 60 pounds as desired, and the trial was actually ended when the boiler ceased to make steam of the pressure of 48 pounds per square inch, *i. e.*, 12 pounds per square inch lower than at the start. As these two errors neutralize each other to a great extent, and as the general results of the trials differ enough to show at a glance that the conclusions to be drawn from the comparison of such results are independent of minor corrections, it was deemed unnecessary to take these into account.

The following is Mr. E. E. Magovern's record of his calorimeter experiments—

Number of Test.	Weight of Water in Calorimeter. Pounds.		Temperature of Water. F. Degrees.		Steam Pressure Pounds per Square Inch.	Duration of Test. Minutes.
	Initial.	Final.	Initial.	Final.		
7	308·5	339·75	77·3	180·3	52	3·067
8	306·5	327·	77·2	147·8	48	2·079
9	306·2	321·95	76·3	127·	43	1·567
10	306·2	320·95	76·	128·	45	1·579
11	309·8	342·3	77·2	186·	54	3·054
12	310·6	329·6	77·	136·3	62	1·496

Item.	Before Change.	With Post and Sawyer Attachment.
Duration of test, hours,	16·	16·28
Wood for starting fire, pounds,	323·5	338·
Coal equivalent of this wood, pounds,	129·4	135·2
Coal put into furnace, pounds,	4652·	3692·
Moisture in coal and wood, pounds,	184·1	136·
Unburned coal picked from ashes, pounds,	713·	417·
Ashes, pounds,	548·	577·
Per cent. of Ashes,	14·1	17·6
Coal burned, including wood equivalent, pounds,	4068·4	3410·2
Dry coal burned, including wood equivalent, pounds,	3884·3	3274·2
Combustible burned,	3336·3	2697·2
Times furnace was fired,	23·	29·
Times fire was sliced,	8·	14·
Times fire was cleaned,	1·	4·
Draught pressure, inches of water,	·14	·30
Water pumped into boiler, pounds,	37620·	29640·
Temperature of feed water, Initial,	62·7	76·4
Temperature of feed water, Final,	187·9	199·1
Steam gauge, pounds per square inch,	50·9	50·7
Barometer, inches of mercury at 32°,	30·05	29·839
Temperature of fire room, dry bulb,	110°·6	107°·2
Temperature of fire room, wet bulb,	95°·9	97°·7
Height of water in glass gauge,	2·84	3·23
Flue temperature,	340°·	293°·
British thermal units imparted by the boiler to the steam generated per pound (by Mr. E. E. Magovern's calorimeter experiments),	958·9	940·4
Real evaporation from actual feed temperature at actual pressure, (by Mr. E. E. Magovern's calorimeter experiments),	35474·	27721·
Equivalent evaporation from and at 212° Fah.,	37340·	28852·
Pounds per hour, Real evaporation, actual condition,	2217·	1703·
Pounds per hour, Equivalent evaporation, at and from 212,	2334·	1772·
Pounds per hour, Dry coal,	243·	201·
Pounds per hour, Combustible,	209·	166·
pounds per hour per sq. foot of grate surf. Real evaporations, actual conditions,	88·7	85·1
pounds per hour per sq. foot of grate surf. Equivalent evaporation,	93·4	88·6
pounds per hour per sq. foot of grate surf. Dry coal,	9·71	10·05
pounds per hour per sq. foot of grate surf. Combustible,	8·34	8·28
Pounds per hour per sq. foot of heating surf. Real evaporation, actual conditions,	1·967	1·363
Pounds per hour per sq. foot of heating surf. Equivalent evaporation,	2·070	1·418
Pounds per hour per sq. foot of heating surf. Dry coal,	·215	·161
Pounds per hour per sq. foot of heating surf. Combustible,	·185	·133
Boiler horse-power, rating a horse-power at an evaporation equivalent to 30 pounds of water from and at 212° F.,	77·79	59·07
Fuel per hour per boiler horse-power, pounds, Dry coal,	3·121	3·404
Fuel per hour per boiler horse-power, pounds, Combustible,	2·680	2·803
Square feet of heating surface per boiler horse-power,	14·49	21·16
Square feet of grate surface per boiler horse-power,	·321	·338
Real evaporation actual conditions, pounds, Per pound of dry coal,	9·133	8·466
Real evaporation actual conditions, pounds, Per lb. of combustible,	10·633	10·278
Equivalent evaporation, pounds, Per pound of dry coal,	9 613	8·812
Equivalent evaporation, pounds, Per pound of combustible,	11·192	10 697

COAL.

The coal used was Scranton coal, stove size, apparently quite dry.

From each barrow weighed during each test, we took a few pieces, and set them aside in the room adjoining the fire room. At the end of the test, we took about 3 cubic feet of the thoroughly mixed pieces of coal, boxed it up and sent it to the laboratory of the Stevens Institute, where we made an average sample, each test, by breaking with chisel and hammer a lot of fragments of 30 different pieces, the sample being then powdered and bottled in a well-stoppered bottle.

For the analysis of the coal, we adopted the scheme described in pp. 102–105 and 135–136 of the third edition of *Notes on Assaying and Assay Schemes*, by Pierre de Peyster Ricketts, according to which we carried through two analyses, agreeing together throughout to within $\frac{1}{1000}$ of the weight of coal analyzed, the record of the last analysis, made on May 10, 1887, being as follows:

	Grammes.
Coal + crucible + cover,	12·675
Crucible + cover,	10·675
Coal,	2·000

Placed the crucible and contents, cover on, in drying oven, heated to 105° C., keeping up that temperature for 15 minutes, cooled, weighed.

	Grammes.
Coal + crucible + cover before heating,	12·675
Crucible + contents + cover after heating,	12·598
Moisture,	·077

Heated 3½ minutes, cover on, over Bunsen burner, then 3½ minutes over blast lamp, cooled, weighed.

	Grammes.
Crucible + contents + cover before heating,	12·598
Crucible + contents + cover after heating,	12·486
Volatile and combustible matter + ½ sulphur,	·112

Heated over Bunsen burner, cover off, then over blast lamp, then ditto at the same time supplying oxygen gas, till the combustion was complete, constant weight, cooled, weighed.

	Grammes.
Crucible + contents + cover before combustion,	12·486
Crucible + contents + cover after combustion,	10·872
Fixed carbon + ½ sulphur,	1·614

Again,

	Grammes.
Crucible + contents + cover,	10·872
Crucible + cover,	10·675
Ash, including phosphorus,	·197

For the determination of the sulphur another portion of the powdered coal was used.

	Grammes.
Coal + crucible,	23·567
Crucible,	21·567
Coal,	2·000

which, after thorough fusion with the prescribed mixture of Na_2CO_3 and KNO_3 and treated in the usual way for the determination of S by estimating it as Ba SO_4, gave—

	Grammes.
Crucible + filter ash + Ba SO_4,	7·815
Crucible (7·677) + ash (·002),	7·679
Ba SO_4,	·126

S = ·137 × ·136 = ·0186.

It so appears that the coal as fed to the furnace on May 5th and 6th contained in unit weight—

Moisture,	·0385
Volatile and combustible matter,	·05135
Fixed carbon,	·80235
Sulphur,	·0093
Ash,	·0985
	1·00000

By actual combustion in the furnaces, the so-called ash amounted to—

$$\frac{548}{4068{\cdot}4} = {\cdot}13469$$

in the test before change, and

$$\frac{577}{3410{\cdot}2} = {\cdot}16919$$

in the test with the Post and Sawyer attachment.

The moisture in the coal at the time of the test with the Post and Sawyer attachment was, by the same process above described, ·0355 per unit weight.

Hence, as disposed of by the furnace unit weight of the coal was respectively:

	Before Change.	*With Post and Sawyer Attachment.*
Moisture,	·03850	·03550
Volatile and combustible matter,	·05135	·05135
Fixed carbon,	·76616	·73466
Sulphur,	·00930	·00930
Ash + unburned carbon,	·13469	·16919
	1·00000	1·00000

CALORIFIC POWER.

We charged in a crucible 50 grammes Pb O, 1 gramme powdered coal, well mixed, covered with 20 grammes Pb O.

Heated this in a furnace to thorough fusion, in about ten minutes; cooled, broke the crucible, cleaned the button of lead reduced, and weighed it.

The theory of this assay is that—

$$2\,Pb\,O + C = C\,O_2 + 2\,Pb$$

$$2\,[206{\cdot}4 + 15{\cdot}96] + 11{\cdot}97 = (11{\cdot}97 + 31{\cdot}92) + 2 \times 206{\cdot}4,$$

whence pure carbon should reduce a weight of lead

$$= \left\{ \frac{2 \times 206{\cdot}4}{11{\cdot}97} = 34{\cdot}4 \right\}$$

times its own weight, so that the multiplier for C. G. S. units of heat is

$$\frac{8080}{34{\cdot}4} = 235$$

nearly, and

$$Pb\,O + 2\,H = H_2\,O + Pb$$

$$(206{\cdot}4 + 15{\cdot}96) + 2 \times 1 = (2 + 15{\cdot}96) + 206{\cdot}4,$$

whence pure hydrogen should reduce a weight of lead

$$\left[\frac{206{\cdot}4}{2} = 103{\cdot}2 \right]$$

times its own weight, so that the multiplier for C. G. S. thermal units in the reduction by hydrogen is

$$\frac{34462}{103{\cdot}2} = 334 \text{ nearly.}$$

It is also to be observed that if the heat is too intense, or if the fused mixture is allowed to be in the fire too long, there is rapid evaporation of the lead, and whereas too much reduction of lead would be impossible, the weight of the lead weighed is apt to be considerably short of the weight of the lead reduced.

We made eight assays, of which three were expected to be short on account of too intense heat, or of having had to keep the crucible in too long, owing to the temperature in the furnace not being high enough to accomplish rapid fusion, and the three, indeed, weighed much less than the average of all; and five, obtained under more favorable circumstances, giving weights about that of the last and mean of the five, as follows:

Grammes.	*Grammes.*
30·369	29·155
29·263	29·708
29·734	

It is usual to adopt the highest weight and calculate the calorific power of the coal, as if the reduction of the lead had been operated by carbon alone. If we should so reckon it, the result would be, in C. G. S. thermal units per gramme of the coal—

$$30{\cdot}369 \times \frac{8080}{34{\cdot}4} = 7133.$$

From the previous analysis, we know we have in one gramme of the coal as fed to the furnace in the first test

·80235	gramme fixed carbon, which at the rate of 8080 should give, ...	6483
(·05135)	gramme of volatile and combustible matter, whose chemical composition it would not pay for our present purposes to find out exactly; but which, judging from more complete analyses made by professional chemists, of coals resembling this and containing about the same per cent. of volatile and combustible matter, it appears safe to assume to be approximately equivalent to—	
·02	Hydrogen, which at the rate of 34462, should give, .	689
And		
·03135	Carbon, which at 8080, should give, ...	253
Also		
·0093	gramme sulphur, which at the rate of 2220 should give,	21
	Total heat of combustion, ...	7446

C. G. S. thermal units per gramme of coal, 7,744 C. G. S. thermal units per gramme of dry coal, 8,628 C. G. S. thermal units per gramme of combustible, 15,530 British thermal units per pound of combustible.

The assumption above in regard to the ·05135 of volatile and combustible matter, gives to unit weight of the coal, the following lead reducing material—

·02 hydrogen.
·83370 carbon.

and if the assumption is true, the lead reduced should be—

	Grammes.
·02 × 103·2,	2·064
·8337 × 34·4,	28·679
Total,	30·743
Whereas, our highest weight was,	30·369
Difference,	·374

equivalent to 10·8 milligrammes of carbon or 3·6 milligrammes of hydrogen per gramme of coal, really a very small quantity in work of such kind.

Assuming that ·015 of the volatile and combustible matter is hydrogen, or that the lead reducing material is

·015 hydrogen,
·8387 carbon,

the lead reduced should be—

·015 × 103·2,	1·548
·8387 × 34·4,	28·851
Total,	30·399

which practically agrees with the highest weight of the assays, as the difference even computed wholly in carbon would run into the deci-milligrammes. Taking then the ·05135 of volatile and combustible matter as equivalent to ·015 hydrogen + ·03635 carbon, the calorific power of the coal as used is—

·80235 × 8080,	6483
·015 × 34462,	516
·03635 × 8080,	294
·0093 × 2220,	21
Total,	7314

(*To be continued.*)

REPORT OF THE COMMITTEE ON SCIENCE AND THE ARTS OF THE FRANKLIN INSTITUTE, ON ALEX. E. OUTERBRIDGE'S METHOD OF CARBONIZING FABRICS, AND OF OBTAINING CASTINGS THEREFROM IN METAL.

[No. 1381.] HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 1, 1887.

The Sub-Committee of the Committee on Science and the Arts, constituted by the FRANKLIN INSTITUTE of the State of Pennsylvania, to which was referred, for examination,

MR. A. E. OUTERBRIDGE'S

method of carbonizing fabrics and casting therefrom,

Reports that Mr. Outerbridge's invention consists essentially in the preparation of organic textile fabrics, such as cloth and lace, and the natural organic structures of ferns, grasses, and the leaves of plants, so that they can be exposed to very high heats without causing a disturbance of their form by destructive distillation.

The material which has been subjected to this process becomes capable of resisting the action of the heat from molten cast iron, and may be used as a part of the surface, or facing, of a mould, for the purpose of producing an intaglio impression of the material in cast iron, or other metal, and which casting can be employed, in the manner of a die, for the purpose of reproducing the design, or figure, upon leather, wood, or metal.

The material to be used as a pattern, or mould, is first dusted with finely-powdered carbon, and then packed in finely-ground carbon within a refractory case, made of cast iron, graphite, clay, or other suitable material. This case is fitted with a lid sufficiently close to prevent such free access of air as would allow of combustion, but which is loose enough to permit the escape of the vapors and gases which are produced by the after treatment.

The case and contents are then placed in an oven, and subjected to a temperature of about 300° F. for several hours, until the escape of volatile matters from the case has ceased.

The case is then removed from the oven, placed in a suitable furnace or forge, and the temperature gradually raised to and kept

at a glowing heat for about two hours, after which it is removed from the fire and cooled.

When the contents are taken out of the box, they are shaken in order to remove the carbon with which they were dusted, and in which they were packed. They are then tested by heating to a white heat in a blast-lamp flame, and, if combustion ceases upon their removal from the flame, the operation of carbonization has been properly conducted, and they are suitable for use as moulds or facings of moulds for metal castings.

The success of the method of preparation consists in first removing the fluid or liquid parts of the structure operated upon, and then so slowly distilling off those constituents which are produced by destructive distillation, that the carbonaceous parts, which are unaffected by the heat, and the integrity of the fibres or structure of the fabric, shall not be disturbed by the too tumultuous exit of the vapors and gases; the exceedingly high temperature at the close of the treatment ensuring the complete expulsion of all volatilizable matter.

The difference of result obtained by heating organic structures from ordinary to high temperature, rapidly or slowly, to expel volatilizable parts, is well shown in the difference in the structure of cokes produced from ordinary bituminous coals in gas retorts, and that from the same coal in coke ovens.

Gas coke, which is made by rapidly heating the coal, is in the form of a spongy, porous mass, weak in structure, insonorous, easily ignited and having the appearance of a mass from which bubbles of gaseous matters have escaped.

Oven coke, which is made by heating comparatively large bodies of coal gradually and continuously for a long period, is of a close-grained structure, capable of sustaining great pressure, or weight, and so compact and dense that it is sonorous. This coke is far more difficult to ignite than the gas coke, and somewhat resembles graphite in its characteristics.

The fact that nearly pure carbon, which is with difficulty ignited, and having the ring of steel, can be produced from wood, flax, hemp, cotton, paper, or silk, by heating them to redness out of access of air in a carbon vapor, or imbedded in powdered charcoal, has long been known.

The committee has no knowledge of any other method of

carbonization, whereby the form or integrity of the structure of fabrics, either natural or artificial, can be preserved intact.

That the product of the method of treatment of organic structure by Mr. Outerbridge is a mixture of pure carbon with a silicious ash, is evident from the results of analysis.

A piece of ordinary muslin untreated yielded of

Moisture,	3·05 per cent.
Ash,	1·53 "

A part of the same strip of material when carbonized by Mr. Outerbridge's method weighed 34·26 per cent. of the untreated stuff, and it contained ninety-five per cent. of carbon. From these results, it appears that 65·74 per cent. of the original material was given off as water, vapors and gases. This carbonaceous residue was consumed with difficulty by the action of strong oxidizing agents, such as chromic and sulphuric acids, and required the use of a very high temperature, with free access of air, to burn it in the determination of an ash, which amounted in weight to 4·43 per cent. of the treated material.

The treatment has then converted an easily ignitible material into one exceedingly difficult of ignition and the method employed has secured at the same time a preservation of the integrity of structure with but slight diminution of dimensions.

The change in the properties of the carbonaceous residue from fabrics, by which it resists the action of highly-heated metal, similarly with graphite or graphitic carbon, permits the use of woven or natural fabrics as moulds, for the cheap reproduction in metal of designs, which could not otherwise be made, except at enormous expense for engraving.

The method of using the prepared fabric as a mould is very simple. When it is desired to pour the metal over it, the ends of material are fastened down, either by the edges of the flask or by pinning, and the gates arranged so that the metal shall flow over and not fall upon it. When the side of the block of metal is to receive the impression, the fabric is secured at the lower edge, and it is floated against the side by the inflowing metal.

When the treated fabric is brought in contact with melted cast iron, there appears to be no more tendency to absorption than there is with graphite. Several members of the committee were present when the exhibit accompanying this report was made in white cast iron.

The committee is informed that the most delicate fabric, such as a lace veil of fine mesh, can be stretched across a mould, and (if the metal be poured so as to rise equally upon both sides of it) that it will remain intact, and when the metal becomes cold, a parting of the metal will be made upon the line of the dividing "veiling," each part having impressed upon it an intaglio image of the fabric.

Paper and card board treated by this method have been employed to divide the metal in a casting, where it has been desirable to do so, for instance, to break the continuity of the metal in the circumference of a circular casting, and thus diminish or prevent the strain otherwise produced upon the internal parts in casting.

The application in the arts of the invention of Mr. A. E. Outerbridge is at present limited to the cheap production of elaborate designs for the ornamentation of castings, or for the production of dies for embossing leather, paper or metallic surfaces, and also for the easy parting or dividing of metal in casting; but new fields of application will undoubtedly be opened when the method is brought into more general use.

The Committee considers that the process devised by Mr. Outerbridge is of sufficient importance in the arts to warrant an award for meritorious invention, and suggest that one of the medals in the gift of the INSTITUTE be awarded to him.

Respectfully submitted,

CHARLES M. CRESSON, M.D., *Chm.*

W. P. TATHAM, C. CHABOT,

H. R. HEYL, ISAAC NORRIS, JR.

Amended by the award of the John Scott Legacy Medal and Premium, and as so amended,

Adopted, October 5, 1887.

WM. D. MARKS, *Chairman.*

Certified as correct. WM. H. WAHL, *Secretary.*

BOOK NOTICES

QUANTITATIVE CHEMICAL ANALYSIS BY ELECTROLYSIS. By Dr. Alexander Classen. Translated from the second German edition, by William Hale Herrick. New York: John Wiley & Sons. 1887.

A student in chemistry once asked his Professor what books he would advise him to get that would contain the latest discoveries and improvements. He was told that it was not so much a question of buying books, as of subscribing to scientific journals. This, of course, is very true; but the difficulty is that the quantity of material now contained in these journals has grown to such an enormous extent, that to hunt through them and sift out the desired facts consumes time that is very valuable to the busy worker. This is particularly true with beginners, and it is certain to be a source of embarrassment to them in their progress in so difficult a science as is chemistry. It is important, therefore, that attention should be drawn to the publication of any work that overcomes this difficulty.

Prof. Classen's treatise has to do with a line of chemical analysis that has heretofore been but little taught in our colleges. Indeed, it is within only the last five or ten years that electrolysis has been applied to chemical analysis to any extent. Prof. Classen has had a great deal to do with its development, as he has been the leading specialist upon the subject. His book is an octavo of 170 odd pages, well illustrated and clearly printed. A very good description is given of the various forms of batteries, dynamos etc.; also, of the apparatus used in distributing, reducing, and measuring the current. A thorough description of the determination of the metals follows, and a more elaborate one of their *separation*. A number of test analyses conclude the volume. The translator gives a variety of practical points and suggestions, resulting from his own experience. Thanks to his familiarity with the subject, therefore, the American edition is in some respects superior to the German original.

The work is one that will be of value to every chemist, if for no other reason than that it is the only treatise on the subject in either the German or English language. H. P., Jr.

ELEMENTARY TEXT-BOOK OF PHYSICS. By Prof. W. A. Anthony, of Cornell University, and Prof. Cyrus F. Brackett, of the College of New Jersey. pp. 527. New York: John Wiley & Sons. 1887.

In this volume, Profs. Anthony and Brackett have completed the work, entitled *An Elementary Text-Book in Physics*, a portion of which was published in 1884.

The first issue, which was styled by the authors Part I, treated of Mechanics and Heat. The book is now completed by the addition of Magnetism and Electricity, Sound and Light.

The completed work differs in many respects from other standard text-books on Physics. We miss in it the cuts of apparatus generally employed in

illustration of the various branches of Physics. Though space is thus gained, and the text-book kept within reasonable limits, we fear that the departure will somewhat limit the usefulness of the work, since a good cut of a standard piece of apparatus goes far, even with a comparatively limited explanation, to elucidate the principles it is intended to illustrate. Where diagrams have been employed by the authors, they are so aptly and clearly described that the absence of the usual cuts is made the more marked.

The order of treatment of topics, viz., Heat, Magnetism and Electricity Sound and Light, does not seem to be as natural as that in which sound and light, precede heat and electricity. It would seem more logical to first discuss the more palpable wave motions concerned in the production and propagation of sound, to follow such discussion by the more subtle waves in the luminiferous ether that cause light, to follow this by the study of the effects of heat, and finally complete the work with magnetism and electricity. This latter study, it would seem especially preferable to defer until a general acquaintance is had with the other departments of physics. However, the order followed by the authors is not devoid of advantages, and may be preferred by some teachers.

Apart from the order of arrangement, it is quite evident that the book is the work of practical teachers. Throughout its pages the phraseology is such as to conclusively show that it was born in the class room. The presentation of the facts is strictly logical, and indicates that long and intimate familiarity that comes alone with repeated teaching. The authors are especially to be congratulated on their success in combining that clearness and conciseness in their text that are so markedly absent in so many advanced text books.

We heartily commend the work for the use of high schools and colleges.

E. J. H.

FLOW OF WATER IN OPEN CHANNELS, PIPES, SEWERS, CONDUITS, ETC. By P. J. Flynn, C.E.

This little compendium of hydraulic formula and tables constitutes No. 84 of the *Van Nostrand Science Series*. In it the author has condensed and compared the several formulæ used for the service indicated in the title, and tabulated the constants so as to save time and labor in calculating the discharge under given conditions of slope, diameter, roughness, wetted perimeter, etc.

For accuracy and despatch, we incline to the opinion that the graphical methods are to be preferred for reading off results where such methods are applicable, and since the publication of the diagram* prepared by R. Hering, C.E., giving the results of the Ganguillet-Kutter formulæ, there is very little room for labor-saving improvements.

C. E.

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* See *Transactions Am. Soc. of Civil Engineers*. 1878.

SCIENTIFIC NOTES AND COMMENTS.

METALLURGY.

TABLES SHOWING RELATIVE VALUES OF IRON ORE CONTAINING DIFFERENT PERCENTAGES OF IRON AND SILICA.—BY JOHN M. HARTMAN, M.E.

Percentage of Silica.

Percentage of Iron.	Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.	20 Per Cent.	25 Per Cent.	Fuel, $2 per Ton.
	40	6·47	5·76	5·05	4·32	3·50	
	45	6·75	6·11	5·43	4·80	4·06	
	50	6·99	6·38	5·77	5·16		
	55	7·20	6·67	6·12			
	60	7·44	6·88				
	65	7·66					
	70	7·90					

Percentage of Silica.

Percentage of Iron.	Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.	20 Per Cent.	25 Per Cent.	Fuel, $3 per Ton.
	40	5·61	4·61	3·81	2·90	1·85	
	45	5·92	5·12	4·24	3·43	2·45	
	50	6·18	5·40	4·66	3·94		
	55	6·42	5·70	5·04			
	60	6·64	6·06				
	65	6·88					
	70	7·12					

Percentage of Silica.

Percentage of Iron.	Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.	20 Per Cent.	25 Per Cent.	Fuel, $4 per Ton.
	40	4·76	3·68	2·58	1·48	·20	
	45	5·08	4·02	3·06	2·23	1·05	
	50	5·35	4·46	3·56	2·72		
	55	5·65	4·77	3·95			
	60	5·85	5·16				
	65	6·09					
	70	6·34					

EXPLANATION OF TABLES.

Table showing price that can be paid for sufficient ore of different percentages of iron and silica to make one ton of iron.

Rule.—To the price shown in table corresponding to the given ore in iron, silica and price per ton of fuel, add the selling price of iron at the

furnace. From this deduct the constant number 12 which gives the cost of ore for one ton of iron.

Example :—Ore containing 40 per cent. iron, 25 per cent. silica, fuel $3, iron $16 at furnace.

$1.85
16.00
$17.85
12.00
$5.85—cost of ore for one ton of iron.

Example :—Ore containing 65 per cent. iron, 5 per cent. silica, fuel $4, Iron $20 at furnace.

$6.09
20.00
$26.00
12.00
$14.09—cost of ore for one ton of iron.

To find the cost of one ton of ore divide the cost of ore per ton of iron by one of the following factors:

FOR ORE CONTAINING IRON.

40 per cent.	45 per cent.	50 per cent.	55 per cent.	60 per cent.	65 per cent.	70 per cent.
2.50	2.23	2.00	1.82	1.67	1.54	1.43

These factors also represent the amount of ore in tons to make a ton of iron.

Example :—Ore 65 per cent., iron 5 per cent. silica, fuel $4 per ton, iron $20 at furnace gives $14.09 for cost of ore.

1.54)14.09($9.15 cost per ton of ore.
13.86
2.30
1.54
7.60
7 70

This table applies to ores containing not over ·5 per cent. sulphur or manganese, to a plant thoroughly equipped with modern appliances making 500 tons per week with economical and efficient management.

PHYSICS.

THE PYRO-MAGNETIC GENERATOR.—The following item of correspondence, which we glean from the *Electrical Review*, September 24, 1887, has a direct bearing on the subject discussed in last month's issue of the JOURNAL, by Mr. Hering, viz.:

"I spent several years endeavoring to produce a practicable motor operating by the remarkable change of iron at a red heat, and brought the results of my investigations and my experimental apparatus before the Committee of Science and Arts of the FRANKLIN INSTITUTE in the winter of 1884–85, for an advisory report.

"The plan I proposed was the same as that adopted by Mr. Edison, namely, using laminated armatures, and alternately heating and cooling them

above and below the critical temperature at which the magnetic change occurs. I filed an application for a patent in the year 1884, but was much discouraged by the fact that at the high temperature oxidation of the heated iron would occur, notwithstanding a coat of plating or enamel.

"The idea of producing electricity upon this plan also presented itself to me; but as the same difficulty would have to be overcome, I considered it impracticable. I have, however, recently devised a plan for heating and cooling which prevents oxidation, and is applicable to a generator; and I am preparing an application for letters-patent in which I will incorporate a certain feature of my motor, which, I believe, was original with me.

"My investigations of the records brought to light an experiment of Prof. Gore, described in *Philosophical Magazine*, vol. xl, p. 173, 1870, in which a rod of iron having a coil at each end, one being connected with a battery and the other with a galvanometer, generated induced currents when the central portion of the rod between the coils was heated and cooled.

"It is true that he was examining the magnetic change in iron, and not endeavoring to produce a generator of electricity; but his apparatus was a generator as truly as Faraday's wire moving across the lines of force was a dynamo."

WM. B. COOPER.

"*No 517 Locust Street, Philadelphia, Pa.*"

CHEMISTRY.

DYEING WITH CHLOROPHYL.—In the *Journal of the Society of Chemical Industry*, **6**, No. 6, are given the remarks of Dr. E. Schunk, F.R.S., on the above subject, as follows:

The author, after referring to a paper on the same subject, by M. J. A. Hartmann, and the report thereon by M. Cordillot, dit Luzy (*Bulletin de la Société Industrielle de Mulhouse*, xxvi, pp. 283–296), mentioned the difficulties to be encountered in endeavoring to fix the coloring matter—chlorophyl—on ordinary tissues, in consequence of its extremely fugitive character, and the slight affinity which it manifests for ordinary mordants. He then described a method by which these difficulties can to a great extent be overcome, so as to impart great relative stability to the substance without impairing its fine green color.

Having obtained solutions of compounds which contain, along with coloring matter, various metallic oxides, such as cupric and zinc oxides, he showed that these solutions impart very little color to cotton, silk, or wool, but that coagulated albumen, gelatin, and more especially the animal products yielding gelatin, such as skin, the ossein of bones, etc., readily attract the color, and are readily dyed when immersed in the solutions. Specimens of leather dyed in this manner were exhibited to the meeting, showing various shades of green, which, in day-light at least, are very pleasing, though by gas-light they share the fate of ordinary greens, and appear dull and dingy. These colors stand the action of soap and dilute acids in the cold, but are not materially improved by the treatment. In the opinion of the author, the tannin of the leather does not assist in fixing the color. The peculiar compounds of color-

ing matter with acids and metallic bases, which the author employed in his experiments, do not yield lakes by treatment with ammonia, being in themselves lakes, which dissolve in alkaline lyes without undergoing any change. It would be possible to modify the method so as to make it practicable on a larger scale, but the cost would probably prevent it being successfully applied, even if the colors obtained were sufficiently bright and intense to make success desirable. H. T.

ON THE TANNIN OF OAK WOOD.—By Dr. Carl Böttinger. *Liebig's Annalen*, **238**, 3.

Commercial oakwood extract is dissolved in water, the clear solution decanted and evaporated to dryness. This dry extract is powdered and treated with acetic anhydride, which forms an acetyl compound, which is separated from the coloring matter by solution in glacial acetic acid. The acetyl oak tannin is precipitated by pouring this glacial acetic acid solution into water. A repetition of the process is required, in order to get a pure product, and such a purification is attended with considerable loss. The analysis by treatment with magnesia gives the formula $C_{15}H_7(C_2H_3O)_5O_9$. This compound is insoluble in water, ether and alcohol, but is dissolved by acetic ether, chloroform and acetone. By heating with water in a sealed tube to 135° C., there results acetic acid and a red brown powder, which is insoluble in water, and is an anhydride of tannic acid. This powder is collected, washed with water, dried at a temperature not exceeding 25° C., dissolved in alcohol, evaporated, and the residue dissolved in water, and evaporated to dryness in a desiccator. The residue is oakwood tannic acid, a light brown powder, hygroscopic and easily soluble in water and alcohol. The ultimate analysis gave the compact formula $C_{15}H_{16}O_{11}$, but on heating to 135° C., two molecules of water were given off, so the formula becomes $C_{15}H_{12}O_9$, $2H_2O$. This tannin possesses some differences from that of the oak bark. H. T.

SKATOL FROM STRYCHNINE. C. Stoehr (*Berliner Berichte*, **20**, 1108). Skatol, which is a peculiar product of the decomposition of albumen in the intestinal canal or by fermentation, has been obtained by the anthor in the distillation of strychnine with lime. The reaction lends support to the theory that one of the two nitrogen atoms in strychnine appertains to a skatol or indol group, while the other is of a hydro-pyridin group. W. H. G.

GLYCERIC ALDEHYDE. E. Grimaux (*Bull. Soc. Chim.*, **47**, 885.)—When dry glycerin is mixed with the slightly energetic commercial platinum black, it soon acquires energetic reducing properties and an acid reaction. But the oxidation proceeds slowly, observations varying from twenty-four to 960 hours, showing that the reducing power (estimated as glucose) attains a maximum equivalent to thirty or thirty-five per cent. of the glycerin. A very active platinum black so energetically oxidizes dry glycerin, that incandescence immediately takes place, and a regular oxidation can only be produced when the glycerin is diluted with twice its weight of water; five grammes of glycerin may then be operated on, using ten grammes of platinum black. The reducing power of the product attains a maximum in between four and eight hours, after which it diminishes, while the acidity

increases. After six or eight hours' contact with the platinum black, the mixture is, therefore, exhausted with water, and the aqueous solution is evaporated to a small bulk in vacuo on a water bath. The reactions of the solution leave no doubt of the presence of an aldehyde; it reduces cupro-potassic solutions, and precipitates silver, in the form of a mirror, from ammoniacal silver nitrate. It becomes brown when boiled with caustic alkalies, or with lime or baryta water; it becomes heated when agitated with a solution of sodium acid sulphite, and alcohol precipitates from the liquid a gummy matter, from which, however, it has not been possible to obtain the aldehyde either with sodium carbonate or with sulphuric acid.

Glyceric aldehyde has the same composition as glucose, and its most important property is that of fermenting under the influence of yeast; carbon dioxide is disengaged, and alcohol is formed, the latter having been identified only by the iodoform reaction in the distilled liquid. The fermentation takes place slowly, and is never complete, this being probably due to the presence of an excess of glycerin, which retards greatly the fermentation of glucose.

Whether the product is really glyceric aldehyde, or a glucose of the formula $C^6H^{12}O^6$, is at present impossible to decide, and the author has only published his results as a measure of priority, Fischer and Tafel having obtained hydrazinic derivatives of the same aldehyde. W. H. G.

THALLIUM IN PLATINUM. H. N. Warren (*Chem. News*, **55**, 241).—After having detected thallium in platinum wire and foil by spectral analysis, the author endeavored to separate the metals. Ten grammes of the wire was dissolved in nitrohydrochloric acid, and after evaporation to dryness and resolution in very dilute nitric acid, hydriodic acid was added, and the thallium precipitated as iodide. The proportions of thallium found varied from 0·02 to 0·1 per cent., the wire containing more than the foil. Alloys of platinum and thallium containing 0·5 per cent. of the latter are useless for wire, and two per cent. thallium gives an alloy fusible at a red heat. W. H. G.

Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, October 19, 1887.*]

HALL OF THE INSTITUTE, October 19, 1887.

MR. JOSEPH M. WILSON, President, in the Chair.

Present, 114 members and eighteen visitors.

Additions to membership since the previous meeting, eight.

The Secretary reported, on behalf of the Committee on Science and the Arts, the award of the ELLIOTT CRESSON Medal to THOMAS SHAW, of Philadelphia, for his System and Apparatus for Automatically Testing Mine Gases, and for Signalling in Mines.